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SELECTIONS

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PAPERS

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PART I.—MAJOR WORKS.

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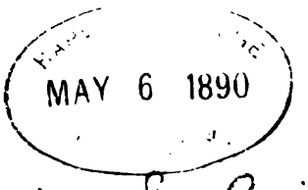

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PAPERS

RELATING TO

WATER-SUPPLY SCHEMES IN INDIA.

PART I.—MAJOR WORKS.

REPORT ON THE CONDITION OF THE MADRAS MUNICIPAL WATER-WORKS, WITH SCHEMES FOR THEIR IMPROVEMENT.

From J. A. JONES, Esq., Assoc. Inst., C. E., Executive Engineer, to Acting President, Madras Municipal Commission.

With reference to G. O. No. 1174, dated 5th April 1877, I have the honour to forward the following Report on the present condition of the Madras Municipal Water-Works, with a scheme accompanied by plans for their improvement.

Surveys when commenced.

2. Since the middle of May last, having been relieved of a portion of my duties in Madras, I have been able to give a great portion of my time for acquiring the information considered necessary by the Chief Engineer for Irrigation; and, in addition to this, I have been able to prepare plans for a scheme which will remedy the defects of the present supply, and which are, in accordance with the views of the Chief Engineer for Irrigation, as stated in his Note No. 145A, contained in the G. O. above referred to.

Necessity of the improvement.

3. It is, however, necessary to point out to the Commissioners, firstly, why some new method of conveying the water to Madras is needed at all, and also to show, besides the scheme to be laid before you, other methods of improving the supply and quality of water to Madras. In doing this I reply to paragraph 4 of G. O. under reference, as to whether it is preferable to filter the water at or near the town or the lake.

Present open channel.

4. The water is at present conveyed to Madras from the Red Hills Lake by means of an open channel which was calculated to deliver about 24 gallons per head per day for a population of 545,000. When designed, it was supposed that the channel would have a good current and the growth of vegetation be thus prevented. These expectations, I regret to say, have not been fulfilled, and at present it is most difficult to keep the channel clear of weeds. This may partly be caused by the intermittent system of supply which we have been of late forced to adopt, and by which method the water is, as it were, dammed up and allowed to rest in the channel for a period of 6 hours during the day and 12 during the night. There is also another evil resulting from this, and that is, that the channel having been thus made into a settling tank, it is getting silted up, and will in time (if allowed to) be so much so as to be unable to deliver the necessary quantity to the town. The cleaning of the channel either causes the water-supply to be shut off from the town, or the delivery of water unfit for drinking.

What channel was intended to do.

5. The foregoing is a description of what the channel now is, not what it was intended to be, as it was intended that the water should continuously flow *through* the channel and not rest in it.

Cause of intermittent supply.

6. The cause why this method of supply has been adopted is that it has not been possible to maintain the Red Hills Tank at as high a level as was anticipated, and as will be hereafter described; the quantity which at most can be drawn off from the tank by the channel is a depth of 15 feet, whereas the total depth of the tank at the lower contours is over 25 feet.

Levels at present off-take.

7. The level of the lowest pipe which draws off water from the tank is 31·31. The full tank level is 46·31, while the tank bottom is in some places at a level of 20·00.[1]

[1] When any levels are given, the datum is mean sea level.

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8. When the tank falls to 31·31, we are unable to draw off any water by our present arrangements; but this is not the only objection which can be raised against the "off-take," for the point of off-take is in such a position that in drawing off the water it passes over a large expanse of slimy mud.

Off-take unsuitable place for drawing off water.

9. It may be safely, I think, said, that so long as the water level of the Red Hills Tank is above 36·00, the water drawn off is in a measure potable, but below that level the water is impure. Madras can then only depend on a supply of potable water when the tank ranges from 46 to 36—impure from 36 to 31; and no water can be drawn (by present arrangements) below that level, although there still remain about 20 millions of cubic yards.

At what level potable water can be had.

10. It cannot be stated with the slightest certainty when the tank will be full again, or that it will be on an average during the year higher than a level 36·00 above which potable water can be had. Madras is therefore in the position of having no sure and certain supply of potable water all the year round,—in fact the probabilities are against such a belief.

Probabilities of future supply.

11. There are other objections to the present channel independent of the height of its off-take. The channel is eminently suited to be a breeding ground for fish and infusoria of all descriptions, and these eventually get into our pipes: did they not do so they would tend to keep the water clean; but as the pipes are not always full, and as these infusoria attach themselves to the pipes, they die when the water recedes from them. They eventually get into the water, which I presume accounts for the smell which sometimes arises from it when first drawn off. I have evidence of this, as the larger mains are covered on the inside with these animals much the same as a ship is covered with barnacles.

Further objections to channel.

12. This brings us to another objection to the channel, and that is, that it is a means of choking the pipes, and would in time considerably impede the flow of water through them.

Pipes likely to be choked.

13. Before leaving the subject of the channel, I think it should be noted that had not the plan been adopted of retaining the water in the channel, and thus making it as it were a settling pond, the probability is that the pipes would have been half full of mud. I judge this from the fact that the channel has silted up in most parts over *one foot in depth*.

Silt in channel.

14. There have been many evidences of late as to what state Madras would arrive at if it were without a supply of water, and as the water must be shut off at intervals of one month or six weeks, and for two or three days each time, under present arrangements, from the town, it must, in a very great measure, be prejudicial to the health of the inhabitants.

Result of impure and imperfect supply.

15. Having thus shown—I hope satisfactorily—that something should be done to improve our present water-supply, I now propose to consider schemes for its improvement.

16. One is naturally led to inquire if the present means of supply can be improved, and if so, in what way. There are four ways in which this can be done—

Schemes for improvement.

I.—To allow the water to come down the present channel and be filtered in Madras.

II.—To cut down the present channel to a level of, say, 25·00 at the head, and keep it 6 feet below its present level all the way to Madras, and then to filter as before.

III.—To cut down the channel as in last scheme, but to filter the water near Koonoor, when the channel is about 6 feet above ground, and then filter it and thence send it to Madras through pipes.

IV.—A similar scheme to No. 3, but keeping the channel at its present level.

17. The first and fourth schemes may, I think, be dismissed with the remark that we can only receive water so long as the lake is above 31·31, and that the filtration of the last 5 feet, in consequence of its impurity, would be more costly.[1] We might of course arrange to have engines permanently at the off-take of the channel, to raise the water when it fell below the level of 31·31; but as we must employ engines at Madras, this double set of machinery would be a most expensive arrangement.

First and fourth schemes need not be considered.

[1] For reasons see page 7, paragraph 36.

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Scheme No. 2 estimate.

18. Scheme No. 2 somewhat detailed would be as follows:—

	₹
Cutting new channel from present sluice to centre of lake	15,000
Rebuilding present head sluice, &c.	3,000
Lowering channel and re-sectioning it from 0 miles to 6·4 miles——cubic yards 4,27,100 at 3 annas	78,830
Removing two aqueducts under channel and replacing by syphons	5,000
Under-pinning eight over-bridges at 1,500	12,000
Rebuilding two under-bridges at 2,500	5,000
Rebuilding thirteen culverts	11,700
Removing and replacing nine wooden bridges	900
Alteration in main from channel to land on opposite side of Otary Nulla	1,500
Construction of filters, tanks, and compensating reservoir from which engines would pump	5,45,000
Engines and boilers, including pumps to raise to a height of 35 feet	2,06,400
Stand-pipe enclosed in tower	4,000
Land	10,000
	8,98,330
Contingencies, 10 per cent	89,833
TOTAL	9,88,163

Ground available for filtering.

19. The nearest available ground on which filters and settling tanks could be constructed is that occupied by Mr. Branson, and the lands adjacent to the north.

Levels of ground and details of levels of works, &c.

20. The level of this ground is about 17·00 above mean sea level. There are two methods of constructing the settling tanks and filter beds—the first being to have the settling tanks partly above ground (say at same level as the channel would then be=23·00), 10 feet deep, and the filter beds with their highest water level at 14·00 or 3 feet below ground; and the second being to have both filter and settling tanks below ground. By the first method, the loss of head below present arrangements would be 15 feet, and by the second method the loss would be 22 feet; but their construction in the former way would be very much greater than in the latter. The latter method is the safer and would require less land.

Pressure in town at present.

21. The water pressure in the higher parts of the town is at present very low.

Height water would require to be raised.

22. The water (taking the second method of constructing the settling tanks and filters), would then have to be raised at least 22 feet to give the same pressure as at present, but it would be expedient to raise it at least 35 feet[1] (this would be 42 feet above mean sea level, and is 10 feet less of head than the scheme proposed to be adopted).

Water not regularly consumed and engine power required.

23. The water is not regularly drawn off, and about half the quantity is drawn off in (say) 6 hours, or 3,000,000 gallons in 6 hours; this would require engines of 90 H.P. nominal or 115 H.P. actual, and would be divided between two engines, and this would have to be increased by a half more, as it would be requisite to have three engines, so that any two of them could do the full work, say 172 H.P. actual. We must either have engines to do this work or must have a compensating reservoir at a height of 18 feet above ground, able to contain at least 240,000 cubic feet, of which the cost at that height would be enormous. The cost of these engines would probably be about ₹1,200 per H.P.=₹2,06,400.

Stand-pipe tower.

24. A small tower is necessary to contain the stand-pipes through which the water would have to be raised, and it would probably cost about the amount put down for it in the above estimate.

Cost of maintenance.

25. The total cost of this scheme would then be about ₹9,88,000, and the maintenance of these engines, works, &c., would be at about ₹646 per annum per H.P. actual at work, which is 115. This, annually, would be ₹74,290, without including the depreciation of the buildings and machinery.

No allowance made for houses.

26. It will be observed that no allowance has been made for houses for men, as might be needed, or for fencing the compound, as would decidedly be advisable, I think, from the proximity of the works to the town.

[1] We must calculate the loss of head at 1 foot above the bottom of the settling tank,—which is the same level as the water in filters—as we cannot keep filling and emptying the settling tanks at the same time without destroying their utility.

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27. The proximity to the town is an objection, as the water is very liable to be tainted by the foul atmosphere. The reservoir into which the water goes after filtration might be covered, but this would again add to the cost.

Proximity to town an objection.

28. Let us now look at Scheme No. 3. It will be advisable to detail it in a similar manner to No. 2.

Scheme No. 3.

Estimate of Scheme No. 3.

	₹
To cut new channel from present head sluice to centre of lake	15,000
Totally re-building present head sluice	3,000
Cutting channel 3 miles six feet deeper than at present, 197,120 cubic yards at three annas	37,000
Pulling down nine acqueducts and replacing by syphons	5,000
Under-pinning four over-bridges	6,000
Culverts No. 9	8,100
Removing and replacing three wooden bridges	300
Construction of filters, tanks, compensating reservoirs, &c.	5,50,000
Engines, including pumps and buildings to raise water 28 feet	1,68,750
Stand-pipe and tower	4,000
27″ main from Koonoor to masonry shaft, 3 miles 4 furlongs, and relaying present four and half with same size of piping	2,19,450
Land	4,000
	10,20,600
Contingencies, 10 per cent.	1,02,060
TOTAL	11,22,660

Schemes No. 2 and 3 compared.

29. The differences between this scheme and No. 2 are—

1st—A less length of channel to cut down, and fewer alterations in bridges, &c.
2nd—An addition of a 27-inch main from Koonoor to masonry shaft.
3rd—A less height to raise the water.
4th—Greater cost in the construction of filters, &c., on account of distance material would have to be brought.
5th—Greater cost of maintenance from a similar cause.

30. The ground at Koonoor being, where the proposed site for tanks, filters, &c., under this scheme is, about 6 feet below channel bed.

Site for filters.

31. The channel at this point would be at a level of 24·00 after being cut down 6 feet and taking a 10-feet settling tank; if we arrange to have the same head of water as in Scheme No. 2, the water would require to be raised 28 feet instead of 35, and making a similar calculation the H.P. nominal required would be 70 and actual 90; but we must add ½ to this for contingencies as before, making 135 H. P. required. The cost would be at ₹1,250 per H.P.=₹1,68,750.

Cost of engines.

32. The cost of the 27″ main is the great difference; in fact, we might have very nearly approximated to the cost of this scheme by deducting half the cost of the alteration on the channel, and adding the cost of this, which comes to ₹2,19,450 for the piping and laying, which might be done below present channel bed. The sides of the channel might, after being cut down level with the bottom, be made available as a road to the works, or it might be filled up for this purpose.

Cost of main to Madras.

33. The cost of maintenance in last scheme was taken at per annum ₹646 per H.P. actual at work, and if we take it on the same rate for this, it would be ₹58,140 per annum. It would not however be the same rate, as there is 3½ miles cartage extra, and this alone would probably cost ₹4,000 a year.

Cost of maintenance.

34. There is one great objection to both these schemes which is that they cannot well be executed without shutting off the water from Madras for some considerable period of time. This objection could be got over (at of course increased cost) by making a parallel channel, the length being determinable on whether No. 1 or No. 2 scheme were adopted.

Objections to Schemes Nos. 2 and 3.

35. In making such a channel, it would be the least expensive way to make it so that one-half of the embankment was the bank of present channel. Such a channel from Red Hills to Madras would probably cost ₹1,50,000.[1] The cost of a parallel channel to Koonoor would be more than half

Constructing parallel channel.

[1] I judge this from the cost of the present channel—₹1,75,000. One-half or 8 miles of channel is in cutting, and the other in embankment; there would therefore be no saving in making a channel 6 feet lower as far as the earthwork is concerned on the first half, but there would be a saving by the earthwork and under bridges on the secondhalf.

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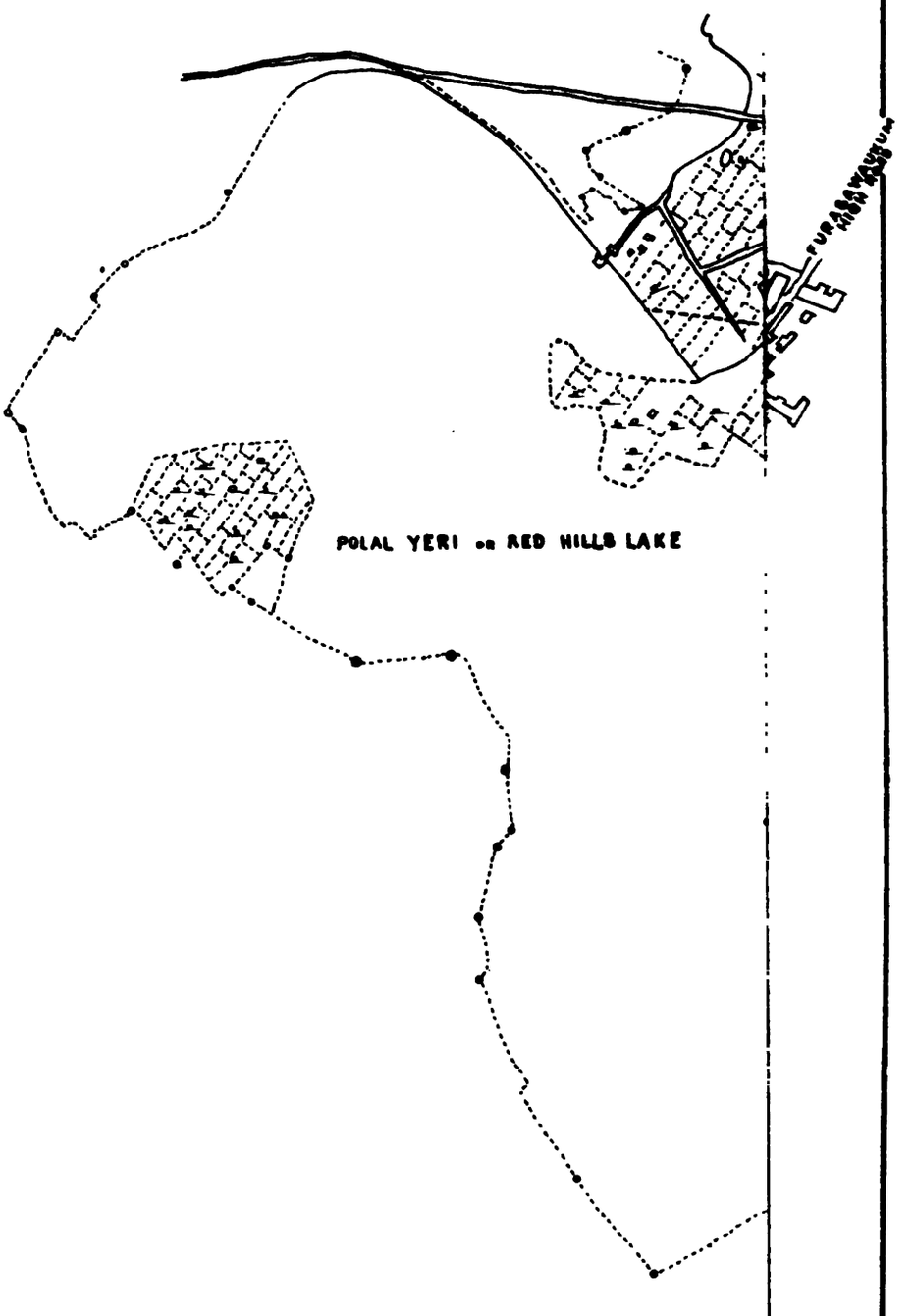
MADRAS MUNICIPAL WATER WORKS

No. 1



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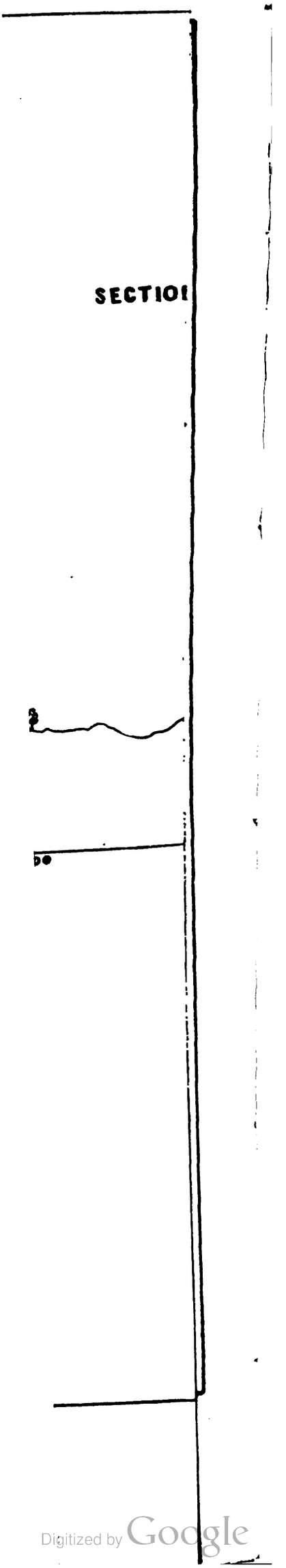

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this amount, as the ground is hard and the excavation would be deep. This I put down at ₹90,000. The Scheme No. 2, with a parallel channel, would then be ₹10,26,740, and Scheme No. 3 ₹11,59,790.

Water delivered from channel impure.

36. It is necessary to point out that water delivered by a channel will be considerably more impure when received into the settling tanks, than if it were taken from a deep part of the lake by a pipe which would always draw off near the surface, and thus the cost of filtration would be considerably increased unless the settling tanks were made large in number or area, so as to allow of a longer time to settle, which would increase the original cost of the works.

Schemes should be further considered.

37. Notwithstanding the objections which I have pointed out to these two schemes, I think they demand careful consideration, though I am not prepared to recommend them when compared with the scheme which I now have the honour to detail:—

PROPOSED SCHEME FOR FILTERING AND CONVEYING WATER TO MADRAS.

Attached to this Report are the following Plans:—

1. Small scale plan showing routes to Red Hills and route adopted	on sheet	No. 1.
2. Large scale plan of route adopted, showing position of tower, pumping station, filtering beds, &c.	on sheets	Nos. 2 to 8.
3. Section of route	on do.	Nos. 9 and 10.
4. Section from off-take to filters	on do.	Nos. 11 and 12.
5. Plans, section, and elevations of tower and gangway . .	on do.	Nos. 13 to 15.
6. Proposed plan and elevation of pumping well, engine and boiler houses	on sheet	No. 16.
7. Plans and sections of settling tanks, filter beds, sand washing machines, &c.	on sheets	Nos. 17 to 19.
8. Map of Madras, showing lines of pipes at present laid and heights above mean sea level	on do.	No.

Off-take.

38. The first point which required to be determined was the position of the off-take, and this I have placed about 900 feet south-west along the bund from the Polal Sluice. Between this point and the sluice, the bed of the tank on a contour parallel to the bund is practically level, and the slightly increased depth which might be had to the north-east does not, I think, warrant the extra expenditure which would be incurred were the off-take placed north-east of the Polal Sluice. Again, to the south-east the tank gets slightly shallower, so that we cannot move further in this direction; the point selected is, I think, decidedly the best place for the off-take.

Position of filters.

39. The next point which demanded attention was the site for the tanks and filters. These I have placed on high ground, as shown, though not quite the highest ground. The loss of head, however, is very little, and indeed the very highest land is not of sufficient area to accommodate all the works. There is another reason, however,—and that the principal one,—why I have placed the work here, and this was to obtain for the filters a ground of slightly less elevation than for the settling tank, as the level of the water in them must always stand about 1 foot above the bottom of the settling tanks to enable the water in the latter to be drawn off to this depth. The third reason is that the construction of the works will be cheaper, as there will have to be less excavation for the reason above stated.

Point of junction with existing mains.

40. Before the route to Madras could be decided on, it was necessary to fix the point of junction with the existing pipes. I have fixed this point at the junction of Brick Kiln, Old Lunatic Asylum, and Purse-walkum High Roads. The reasons which led me to do so are—

1—Because the pipes can be laid by a more direct route from here, avoiding obstacles such as villages, tanks, &c., than from any other place.

2—It is near the large space of ground lately occupied by the Lunatic Asylum, and on which I propose eventually building a reservoir, as will be hereafter described.

3—This point is on the 42″ main.

4—The route to the end of the 42″ main at the masonry shaft would be longer.

Alternative routes.

41. Having thus fixed the ends of the routes, the alternative routes were next considered as shown in sheet No. 1.

Route decided on.

42. I decided on the route marked No. 1 through Perambore for the following reasons:—

The other routes.

43. The route by the road is too long, and that marked No. 2, though slightly shorter than No. 1, passes away from roads.

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Reasons for selecting route.

44. The route marked No. 1 is altogether the most favourable. It is the nearest road along which the piping can be easily carted, and I think this is a great desideratum. It passes near the Perambore Works of the Madras Railway, where there are a large number of people who will gladly use the water, and the Company itself, I think, will be glad to take advantage of it. The route avoids all tanks through which piping could not be laid in the wet season. It avoids passing near houses or through any property which might be injured in laying the piping; and it, as far as possible, avoids topes through which it is costly to lay piping, and which might probably injure the pipes in future, or render it difficult to get at them in case it were required to do so. It was impossible, without increasing the length of the piping considerably, to avoid these topes altogether. The route also passes near the Lunatic Asylum, which may also be provided with a branch.

Further reason.

46. Again, nowhere does the ground rise suddenly so as to cause deep excavation in order to avoid raising the piping above the line of virtual declivity. The principal reason, however, for the selection of the route is, as stated before, its proximity to roads.

Why piping should not be laid along road.

47. It would be expensive, on account of the small culverts under them, to lay the piping along the roads, and all severe bends have been avoided.

Depth at which piping will be laid.

48. I propose to lay the top of the piping on an average 3 feet below the ground, which is far below the depth of any ploughing operations.

Filtration should not be done at Madras.

49. Before proceeding to describe each detail of the scheme, I think it proper to point out why, in this scheme, filtration should not be done at Madras.[1]

Giving reasons for the above.

50. In the first place we should require engines to raise the water from the lake; if raised high enough, we might reduce the size and therefore the cost of the main to Madras below what it is in the scheme I propose.[2] But this advantage is more than counterbalanced by this, that unless at Madras we have a compensating reservoir at a high elevation, we must have engines of double the power we would otherwise need, and still a compensating reservoir at a low level from which they would pump, so as to allow of filtration proceeding regularly, and we must also have engines at the Red Hills—and that of very little less power than the *only* engines in the scheme I am proposing. Indeed, there is no advantage to be had—even the cost of construction will be more, if laterite be the material selected at Red Hills—in having the water filtered near Madras; and, as I have before stated, it is on many grounds objectionable. There is no ground higher than about 10·00, and this is below many parts of the town.

Water Tower.

Position and levels.

51. This I have placed at the point previously described, and at a distance of 74 feet from the top of the inner slope of the bund. It is not quite at the lowest level of the bed of the tank, but a small channel will be constructed as shown, so that water can be obtained down to the full depth required. The lowest level from which I propose to draw off is 22·00. The tower I propose to found at a level of 14·00 on concrete made of Morgan's cement, which could be lowered through water if necessary, should a difficulty be found in laying the foundations. The level of the bottom of this concrete is 8·00 or 12 feet below the lowest level of bed of tank; and from what I have seen in late excavations, I believe that this depth will probably be found sufficient. Its internal dimensions are 8 feet at level of girder at top, and 9 feet at bottom. It is hexagonal, and divided by a central wall. In one-half of the tower thus divided, a stand-pipe is placed with branches through the water into the other half, which is in direct communication with the waters of the lake. In the former part are the valves, which are always thus free from water and able to be put in repair and to be inspected at any time. The mouths of the pipes of the latter division are closed when necessary by balls which are moved by a crab up or down on iron rods as shown on drawings. The lowest pipe of all has not this arrangement, as it will only be required to be in use when the water is very low, and when it is therefore accessible in either division of the tower. As this

Description of tower.

Machinery in tower.

[1] See note by Secretary to Government, Department Public Works, Irrigation.

[2] It would not require to be raised quite to the level of the proposed filter beds to do this, as the size of the main in the scheme proposed is increased on account of the water not being drawn regularly all day, and in this alternative proposal, the compensatory reservoir would be in Madras.

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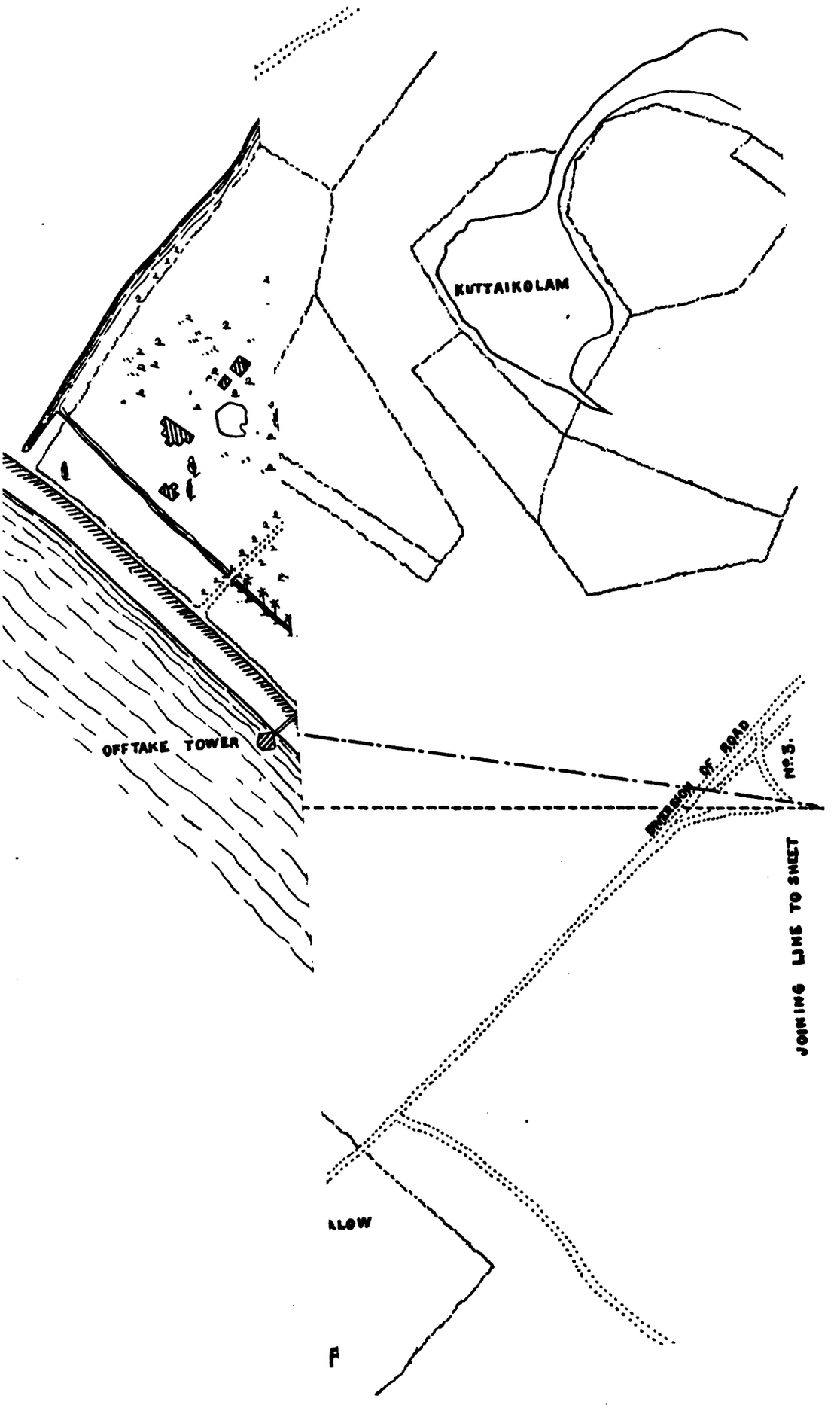
SHEET No 2.



(Sd) J. Lyall

Executive Engineer.

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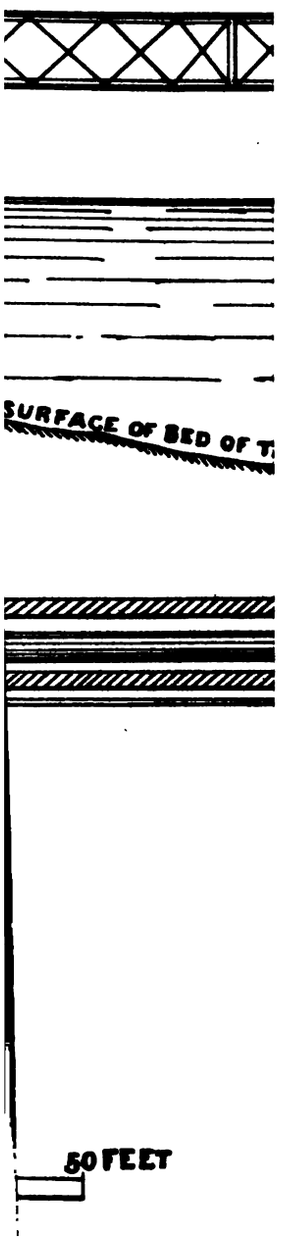

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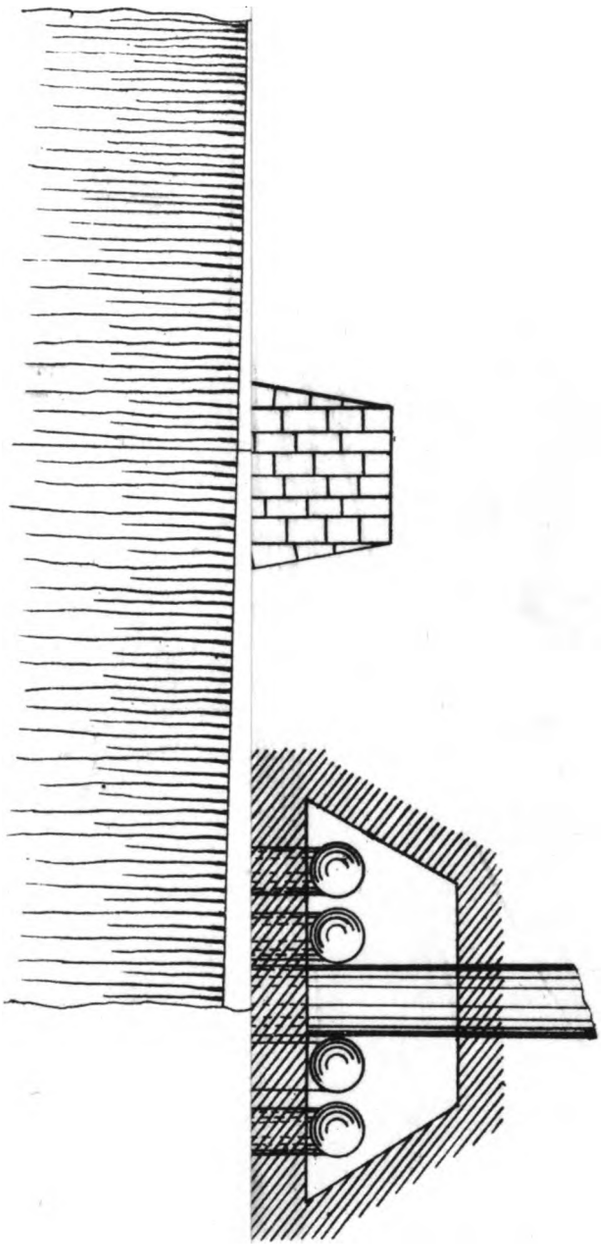

TOWER SHEWING PIPES

FEET

0 6 12 FEET

(Sd.) J. L. Jones

Executive Engineer.

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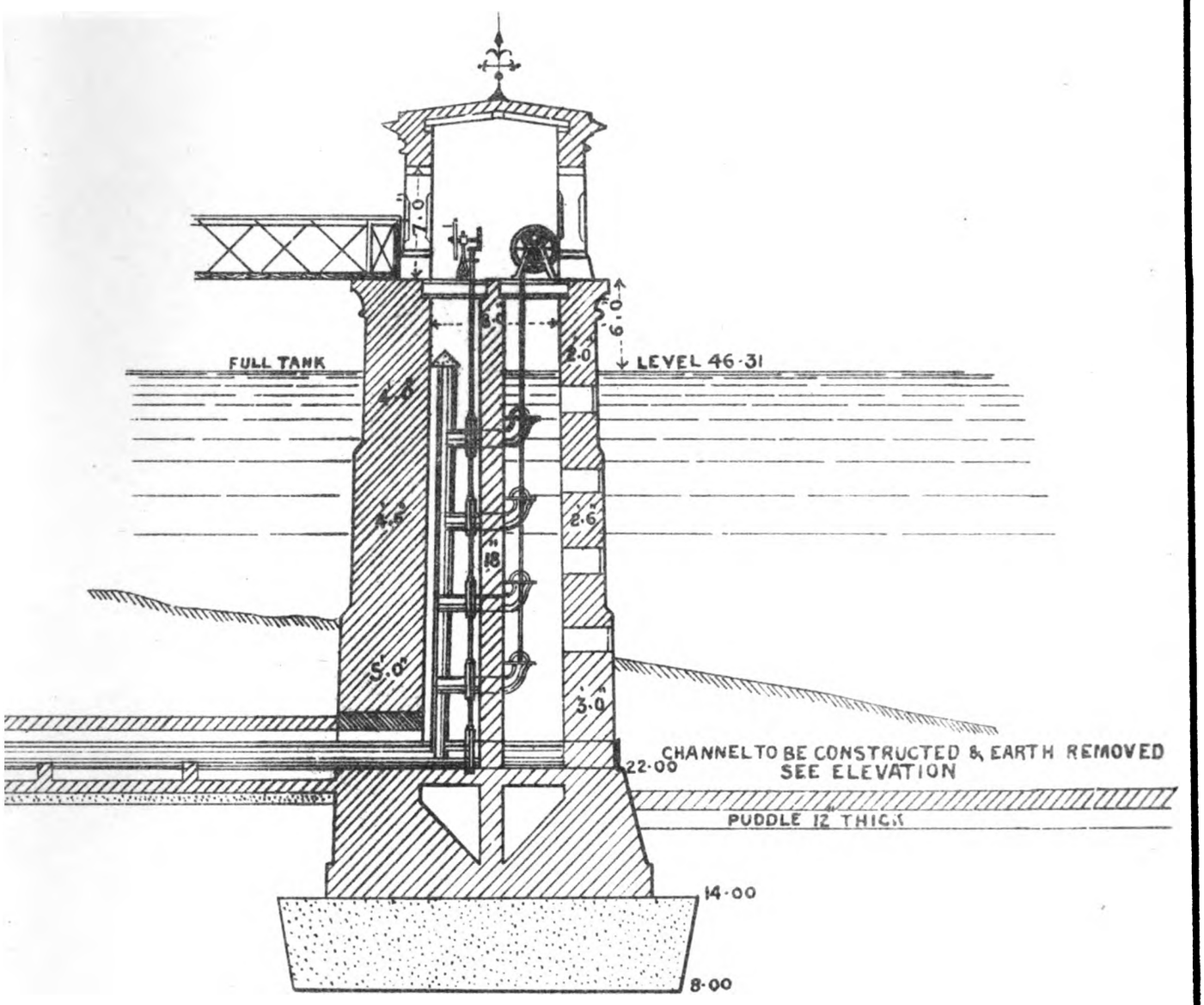

SECTION OF OFFTAKE TOWER SHEWING VALVES

15 FEET

(Sd) J. L. Smeed

Executive Engineer

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Girders for supporting machinery.

pipe will only be used when the water is very low, and when the head at the pumping well is very little, it is of greater diameter than the other off-take pipes. On girders in the upper part of the tower rests the machinery for regulating the valves, and these are covered by the small tower. Gratings will be fixed in entrances through the tower to the pipes. The tower I propose to be in brickwork, pointed with cement.

Culvert.

52. I have shewn a culvert for conveying the pumping main from the tower through the embankment, and this has an entrance, placed, as shown, beyond the outer face of the bund.

Culvert shown on plans.

53. I have shown this in deference to the views of the Chief Engineer for Irrigation, but I beg to submit, for consideration, whether such is needed, and whether a large amount of clay puddle round the pipe, and two or three collars of brickwork at intervals might not prevent any flow of water from the tank through the bund. The present bund has no clay puddle wall as far as I am aware, and this may be a reason against the alternative proposal. I however record such for consideration.

Culvert may possibly not be required.

Support for piping.

54. If the culvert be constructed, the piping will be supported on cross walls, each nine feet apart, as shown.

Entrance to culvert.

55. The entrance to the culvert will be covered over, and a trap door placed in the cover with a ladder underneath for admission.

Gangway.

56. The gangway consists of two lattice girders, their top and bottom rooms formed of T irons, and their bracings of flat iron. The flooring will be supported on cross angle iron as shown. The top of the girders will be cased in wood to form a hand-railing. The gangway is divided into two spans each of 33 feet by a pier, and one end of one span rests on the tower built to receive it as shown, and the opposite end of the other on the bund where a block of masonry will support it. The gangway will be 5 feet in width. Detail drawings, sheet No. 14, are given which fully explain the design.

Construction.

Two spans.

57. It is somewhat difficult to estimate the cost of the tower and culvert, as it will greatly depend on the state of the tank at the time of construction. I have thought it therefore proper to allot a considerable sum for dams, pumping water, &c., &c., and think that R3,000 will probably cover all expenses of this kind.

Estimating cost of tower culvert.

Position of Engines and Pumps.

58. It is hardly necessary to point out that the pumps must be so placed and so constructed that they can be able to draw from the bottom of the lake; but by making the pumps atmospheric and forcing, we can place them, say, at any level between 22·00 and 42·00 above mean sea level. I have made this remark as I do not consider that the pumps should be placed immediately behind the bund. The foundations would in all probability be very soft, and after examination of this site, I am led to believe that there is a leakage through from the tank underneath the bund. The foundations for the engines and pumps at this site would be most expensive, and as the ground is also liable to flooding, they would require to be raised considerably above its level. There is, again, the risk that the operations in excavation might tend to create a rush of water through the bund, and the continual vibration of large pumping engines would not, I think, be favourable to its safety. On the plan, I have marked two sites, Nos. 1 and 2, where I think they would be favourably placed.

Positions proposed.

Foundations unsafe at back of bund.

Probable injury to bund.

59. I am not sufficiently acquainted with the construction of the force pumps used in water-works to state the following positively, but I believe that at whatever level they are placed they will require to pump from that level whether the tank be at a higher level or not; with, however, an atmospheric pump, we can always draw safely 20 feet, and on this account I prefer site No. 2, which is at a higher level, because we would be able with an atmospheric and force pump to take the full advantage of the level of water in the lake, and only have to draw from that level. Thus, suppose the inlet valve of the pump were at a level of 42·00, if the tank were at 42·00 we should only have to force from 42·00 up to the level of the

Force pumps.

Atmospheric pumps.

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filters, and at most only have to draw between 42·00 and at whatever level the tank stood. If this same advantage is to be gained by a force pump, then there is no advantage in site No. 2, except, perhaps, that is on more accessible ground, and not so liable to floods as site No. 1. There is, however, an objection to site No. 2, and it is this, that we must draw atmospherically through 3,000 feet of iron piping. There is no doubt that the pipes could originally be made air-tight, but it is difficult to say how long they might remain so, or what it would cost to keep them so. This is a point I leave for consideration. It would be expensive to put a force or lift pump at site No. 2, and therefore, if the objection as to atmospheric pumping is thought too great, site No. 1 should be adopted—when we would not need air-tight pipes. The pipe from the collecting tower should have a slight fall towards the pumping well at site No. 1, so that the level of the bottom of the well at that site would probably be about 20·00; the ground level is about 32·00.

Drawings of pumps, &c., not given in detail.

60. I have not given detail drawings of the well and pumps, but only a plan of the engine house, boiler house, &c., with the pump well, which are sufficient to show the arrangements I propose (sheet No. 16).

Engines.

61. The amount of water required to be raised from a level of 20 feet to a level of 70 above mean sea level is 6,000,000 gallons per day.

62. The power required for this is found by the following calculation :—

Calculations for engines.

$$\frac{6{,}000{,}000 \text{ gallons.} \times 10 \times 50 \text{ feet.}}{33{,}000 \times 24 \times 60} = \text{say } 64 \text{ H. P.}$$

(hrs. / min. / lb)

This, however, is only the nominal H. P. required. It is necessary to have reserve power in case of accident, and I therefore propose three engines, any two of which can do the work, so that we require three engines each 32 H.P. nominal.

Actual H. P. required.

63. For engines of this H.P. (nominal) about 7″ of area for each H. P. is allowed by the makers, and taking the steam at 30lb pressure over six inches, and the speed of the piston 200 feet a minute, we have the actual H. P. for which amount we must estimate, *viz* :—

$$\frac{\text{H.P.} \times \text{inch.} \times \text{lb} \times \text{feet}}{33{,}000} = 41\,^{1} \text{ H.P. actual.}$$

This is the amount for which I have allowed in the estimate (3 engines of 41 H.P. each). We have already seen that the area of the cylinders is 224″, therefore the diameter $= \sqrt{\frac{224}{\cdot 7854}}$ = 17 inches.

Stroke of engine.

64. The stroke is usually twice the diameter; this gives 34″ = 2·83 feet.

This brings us to the calculations for the size of the pumps.

Pumps.

Number of pumps.

65. Let there be three pumps, any two of which can do half the work, therefore each pump must raise $\frac{6{,}000{,}000}{2}$ per day or $\frac{668}{2}$ cubic feet per minute = 334 cubic feet. The length of stroke I propose to be the same as the piston of the cylinder, *viz.*, 2·83 feet, so that $\frac{200}{2 \cdot 83} = 70$ = strokes per minute. The capacity of the pump must therefore be $\frac{334}{70} = 4{\cdot}8$ cubic feet, and as the length of stroke is 2·83, the area of the pump will be $\frac{4{\cdot}8}{2{\cdot}83} = 2$ feet area, or say 1-8, diameter, for each pump.

Engines proposed.

66. I propose to make the engines direct acting, and place them over the pumps, which are in a well 20 feet diameter.

Engines how supported.

The engine framing will be supported on girders laid across the well, and disposed above the pumps as shown in drawings of engine house. The pumping main will divide into three and join each pump. Each pump will have its own air vessel into which the pipes from the pumps will be led, and after leaving the air vessel, they will join again into one main. This plan of placing the engines over the pump well and using it for their foundations leads to economy not only in them,

Economy in foundations.

but also in allowing of the reduction of the size of the engine house. A similar plan has been adopted at the Eastbourne Water-Works with success. The air vessels should be of about 38 cubic feet in capacity.

[1] It is supposed that this amount will also cover the extra head due to friction in the pumping main.

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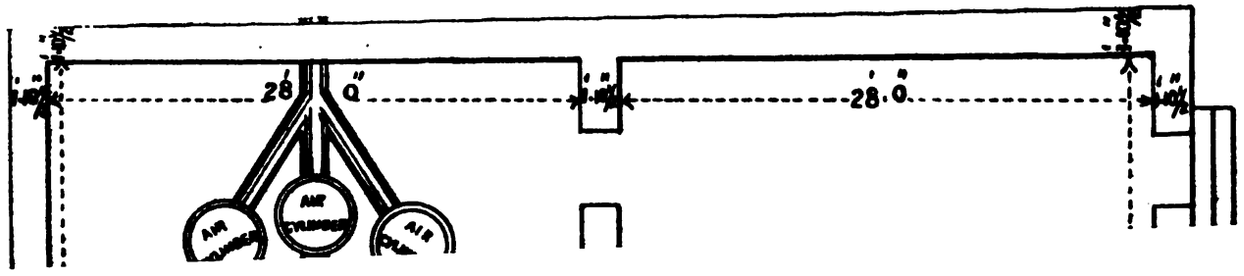

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MADRAS MUNICIPAL WATER WORKS –

SHEET Nº 17.

SECTION THRO A.B.

SECTION THRO CD.

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MADRAS MUNICIPAL WATER WORKS_ IM

SHEET N

SECTION THRO: C D.

ENLARGED PLAN AT COLLECTING WELL

SECTION OF COLLECTING WELL SHEWING ARRANGEMENTS FOR RUNNING FILTERS DRY

SCALE 01 FEET

(Sd) J. L. Mules

Executive Engineer

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67. The cost of pumping engines varies very considerably. The cost of the engines at Cork Water-works (Sir J. Benson) was £55 per H. P., and at the London Sewage-works the engines were estimated at £70 per H.P. Both the above included engine and boiler houses, chimneys, &c. The Board of Health have adopted a standard of £50 per H. P., and Mr. Neville, in his work on Hydraulics, says that the cost per H. P. will vary from £50 to £100. I have taken the extreme limit, and put the cost per *H. P. nominal* at ₹1,200, allowing for contingencies and carriage, exchange, &c. This amount will, I think, cover all probable expenses, and I include the engine house and buildings in this sum.

Cost of engines; cost at other places.

Pumping Main.

68. I propose that the pumping main be 18″ in diameter. The amount of water raised per minute by the engines is 666 cubic feet, and this would equal a velocity through one pipe of 6·0 feet per second, which is not excessive. This main should be furnished with two or three intermediate stop valves to prevent the water returning in case of accident, and a loaded blow-off valve will also be necessary for each pump.

Size of pumping main.

Filter Beds and Settling Tanks.

69. These are fully detailed in the drawings attached to this report, see sheets Nos. 17 and 18. In designing them, economy and convenience have been strictly studied. By the plan adopted the filter beds are placed as far as possible on ground lower than the settling tanks, and the compensating reservoir is placed on the lowest ground of all. Though ground in this locality is not valuable, compactness in the design is advisable for other reasons. The filters and tanks can be more easily supervised, the length of connecting piping between them is of less length, and the regulating valves are placed together as far as possible for easy access, and for speedy and convenient working.

Details in drawings.

Filter beds on lower ground than tanks.

Compactness in design desirable.

70. There are six settling tanks, five filter beds, and one compensating and service reservoir Each settling tank has an area of 45,000 square feet. They are nine feet deep, but only 8 feet will be available for drawing off into the filter beds, the remaining foot in depth being available for impurities which will be deposited. These six tanks are therefore able to contain—

Number of settling tanks and filter beds.

$$45{,}000 \times 8 \times 6 = \underset{\text{cubic feet.}}{2{,}160{,}000} = \underset{\text{gals.}}{13{,}500{,}000}.$$

As, however, one tank will always be out of use for the purpose of cleaning, we can only calculate on 11,250,000 gallons; as each tank holds 2½ million gallons, it will take 9 hours to empty itself—so that it will take 45 hours to empty the five tanks. As, however, it will also take 9 hours to fill each of them, we must deduct this amount, and thus the water will be allowed 36 hours for settling when only five tanks are in use, but 45 hours when all the six are in use. This time, I think, will be sufficient for whatever state in which the Red Hills Tank may be. When the tanks require to be cleaned, the remaining water in them will be left off by a drain which is sunk below the level of the tank, and towards which the beds of the tanks slope. The drain is on a gradient of 1 in 500. The beds of the tanks being a smooth surface, they will be readily cleaned, first by washing them with running water 12″ deep, and by then attaching a hose to the supply pipe of the tank. These drains will be led into tanks which are around the base of the hill; the water may therefore be made available for irrigation or other purposes to a small extent. These drains will be partly tile drains, and partly open cuts or channels.

Time of filling and emptying tanks.

Filter Beds.

71. There are five filter beds, one of which will always be out of use for cleansing purposes. They have each an area of 2,336 square yards, or, with 4 filters, 9,344 square yards. The rate of filtration will be 642 gallons per square yard in 24 hours, which thus gives 6,000,000, which is the quantity required. This would be about 5·5 inches per hour. The rate of filtration to be efficient should never exceed 6 inches per hour. This rate has however sometimes been exceeded, and the following table exhibits the rates at a few of the English Water Companies' filter beds:—

Rate of filtration.

Rate of Thames Company.

	Inches per hour.
Chelsea	6·4
East London	2·5
New River	4·5
Southwark and Vauxhall	3·0
Lambeth	10·7

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Red Hills water is not so foul as Thames water.

Supply to the filter beds.

71. Each filter bed can be supplied with water from any of the six settling tanks.

Distribution how effected.

73. In leading the water from the settling tanks, the pipes leading it from a pair of tanks unite and pass into a collecting well, and from this well pipes lead to all the five filter beds. These pipes enter the filter beds at a slightly higher level than the top of the sand; the regulating valves are placed at the various collecting wells.

Filtering media.

74. The filter beds as designed show three feet of water above the filtering media, which are—

2 feet fine sand.
1 foot sand size of shot.
1 foot gravel size of walnuts.
1 foot gravel large size.[1]

Drains for conveying away filtered water.

75. In the lower layer are the drains 6″ and 9″ in breadth according to their position in the filter bed. I propose that they be of 4½″ brick walls and flat tiles laid over them. The bricks will be perforated, as also the horizontal tiles; these, it is probable, can be made in this country.

Formation of sides and floors of filter beds.

76. There are two available methods of forming the sides and floors of the settling tanks and filter beds. They are—first of brickwork laid in chunam and pointed with cement, and second, laterite similar to that used in the Red Hills Tank Bund and plastered with Morgan's or Portland cement. I have estimated for executing the works in either way; in either case I propose to lay the masonry on puddle one foot thick.

Collection of filtered water.

77. After filtration, the water is carried by drains and pipes into the main collecting well. The pipes from Nos. 1 and 2 filters will be carried under filter No. 3, and the pipe brought to the same level at the well as the pipes from the other three filters. From this collecting well the water is led into the compensating and service reservoir.

Clearing out filters.

78. When the water is required to be completely led out of any filter in order to clean it, this will be performed by closing the valve leading to the main collecting well and opening the valves on the pipes in connection with the lower part of this well, which has a double bottom (see Drawing No. , sheet No. 18). The water is discharged from the under part of this well by a 12″ stoneware pipe as shown on drawing. It will therefore be noted that the arrangements for regulating the flow of all the filters is at this well, in addition to the appliances for completely exhausting the water from the filters.

Service and Compensating Reservoir.

Extent required.

79. Were the water drawn off in the city at a regular rate, this would not be needed, but as the water is not so, we require, so as to allow of filtration proceeding regularly, to keep a certain quantity of water in reserve. The quantity required in 24 hours is 6,000,000 gallons. Of this, however, one half or 3,000,000 gallons is drawn off in 6 hours, but as the filters only pass 1,500,000 gallons in this time, we require to make up for this difference of rate in receipt and supply. It is also necessary to keep always a head of water above the pipe. I have allowed for a reservoir able to contain 2,000,000 gallons if necessary, but except in exceptional circumstances, all this quantity would not be needed. The following shows approximately the varying rate at which water is taken in Madras :—

			Gallons.	
		Let	1,500,000	be the amount in tank at 6 A.M.
3 hours	Filtered from A.M. 6 to A.M. 9		750,000	
			2,250,000	
	Drawn from 6 to 9		1,500,000	
			750,000	This will be the amount in tank, 9 A.M.
6 hours	Filtered A.M. 9 to P.M. 3		1,500,000	
			2,250,000	
	Drawn P.M. 9 to P.M. 3		1,000,000	
			1,250,000	do. do. at 3 P.M.

[1] The supply of filtering material is an important point. Sand can be had best I fancy from the Cortilliar River. Small gravel may be got at the Red Hills; their upper strata are composed of it. It would, however, require extensive washing. Larger gravel might probably be had from the Cortilliar, but there can be little difficulty in procuring this. The lower layers of the filter beds seldom, if ever, require renewal.

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			Gallons.	
3 hours	Filtered	3 to 6 . . .	1,750,000	
			2,000,000	
	Drawn	3 to 6 . . .	1,500,000	
			500,000	This will be the amount in tank, at 6 P.M.
		A.M. A.M.		
12 hours	Filtered	6 to 6 . .	3,000,000	
			3,500,000	
	Drawn	6 to 6 . .	2,000,000	
Total 24 hours			1,500,000	do. do. at 6 A.M.

N.B.—It will be observed that half the quantity is drawn in 6 hours, *viz.*, from 6 to 9 A.M. and 3 to 6 P.M.

The lowest at which the tank stands is 500,000 gallons, and the height of the water when the tank holds 2,000,000 gallons is 10 feet; there will therefore never be less than 2½ feet in the tank, or perhaps rather more (say 3 feet), as the tank has sloping sides. As designed, the level of the water is to stand at 69·00 in the settling tanks above mean sea level, and in filters 8 feet lower or 61·00; and when the compensation reservoir is full with 2,000,000 gallons it will stand at same level of 61·00.

80. The general plan of tanks and filter beds also shows the following:—

Turncocks' quarters.
Valve houses.
Stores.
Offices.
Sand-washing box.

With the exception of the latter, these do not need to be described in detail; they are included in the estimate.

81. The sand-washing box (Sheet No. 19) may however be briefly described. It is a large box formed of brick-work having two floors with 9 inches space between. The upper floor is formed of perforated cast-iron plates, and on this the sand to be cleaned is laid; between the floors the water is admitted at some pressure from the pumping main. It enters between the floors and passing up through the sand, which is being vigorously stirred by men with peculiar spades, carries off any earthy substance with it. The box is divided into three tubs, so that a large or small quantity can be washed. Two of these boxes are shown on the general plan of the filter beds, &c., and have attached sheds for storing sand cleaned, and that not so.

Pipes, Valves, &c.

82. On the pumping main reaching the main valve house, it is divided into three branches to the three pairs of tanks, and in this house are the valves for cutting off the supply of water from any pair of tanks. On approaching the settling tanks, each branch is again divided into two, with valves to each tank. From the valve house just referred to, there will be an electric communication with the engine house regulating the supply from the pumps to the settling tanks, or a self-acting communication could be made by allowing the water when it gets high enough in the tanks to run back through a small pipe to the engine house and blow a whistle. This valve house should be erected with an upper story, so as to allow of the levels of the water in the filter beds and tanks being carefully watched. The next most important valves are these at the main collecting well (see Drawing No. , Sheet No. 18). There will also be a valve on the main from the reservoir to the town, and valves will also be placed on the other pipes where necessary.

Main from Reservoir to Madras.

83. The size of the main depends on the quantity to be supplied, the rate at which it must be supplied, and the head of water obtainable. The quantity to be supplied is 6,000,000 gallons per day, but at some hours of the day the demand will exceed this. We must allow in calculating the diameter of the pipe for the greatest possible demand, and this will be about double the average demand, so that the main must be able to supply at the rate of 12,000,000 gallons per day. This quantity equals—

Size of main.

Quantity it must be able to carry.

Gallons.		c. ft.	
12,000,000	=	1,925,544	in 24 hours.
500,000	=	80,230	in 1 hour.
8,333	=	1,336	in 1 minute.
140	=	22	in 1 second.

The bottom of the service reservoir at Red Hills is 51·00, but the lowest level of the water in it will be 54·00 above mean sea level, as before shown. The point at which the

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present main is met in this scheme is at a level of 2·00, and this gives 52 feet of head. I calculate only however for 50 feet head. The 42-inch main towards the town is about the same level; at some points the branches are higher. This will not, however, to a great extent influence the calculation for the main.

84. I have calculated the diameter of the main by the two following formulæ, which give the results set against them :—

	Inches.
[1] Beardmore's, which gives the diameter as	34·40
[2] Hawkesley's do. do. as	37·33

By Neville's tables the velocity of discharge from a 36-inch pipe under same conditions is 38·8 inches per second, and this would give 22·2 cubic feet per minute, which is the amount we require.

Calcutta main.

85. In Calcutta the size of the pipes was determined by *Hawkesley's* formula, and calculated to supply 6,150,000 gallons per diem at an average rate (the compensating reservoir is in this case at end of the main next Calcutta); but by experiments made in 1870, it was found that the actual discharge was at least 8 millions gallons—an increase of 30 per cent. I think I am therefore warranted in estimating for a 36-inch main, and this is what I have done.

Present Madras main.

86. The present main (42″) is of course larger than this, because it has less head (23 feet less); but as this head is obtained only half a mile distant from the point of junction, the pipe is on that account less in diameter than it would be were this head obtained at Red Hills or a similar distance away.

87. I think it will be expedient to replace the part of this main between the point of junction and the masonry shaft by smaller pipes suited to the consumption of the few houses it supplies. The part between the junction of the new main and town end of the old main should also be removed and replaced by 36-inch pipes. The question mooted in G. O. No. 1174 of 5th April 1877, as to the advisability of moving these 42-inch pipes to part of the route between the Red Hills and Kilpauk, demands a reference. It would evidently not be proper or expedient to place the pipes directly next the reservoir, as on this part of the route we have a greater inclination than on any other, and less size of pipe than 36-inch in diameter should probably be used here, so as to keep up a proper train and a pipe of greater diameter than 36″ between this part and Madras. There can be no doubt that these 42-inch pipes cannot be laid on this latter portion of the route without continuing them all the way to Madras, and the expense of such a proceeding debars us from it. I do not at present see where these pipes can be used at all.

Valves, &c., for main.

88. The main should be furnished with scour cocks and self-closing valves which would close on any burst taking place and causing a great increase in the velocity of flow. Air valves will also be needed, and a few stop valves should be provided to divide the main into short districts to enable it to be readily repaired if need be.

89. I have now described the works which I propose, I think, fully enough to show their main points, and to enable it to be said whether they can be executed for the amount set down in the estimate.

Storage reservoir.

90. There is however another point to be referred to, and that is the construction of a storage reservoir in the old Lunatic Asylum compound, the cost of which I have not included in the scheme. The level of the ground is about 12·00 and its area is about 11½ acres. The highest points which we need to supply are at a level of 20·00. It is therefore evident that any reservoir must be above the level of the ground. I propose that if it is thought absolutely necessary to have a storage reservoir, to construct it so that its highest water level may be 10 feet above ground level, or a level of 22·00; if the reservoir were made of an area equal to about 384,000 square feet, for which there is an ample space, the reservoir would hold four days' supply, and this is a much greater time than the main, if properly laid, would ever take to repair. Two days might be taken as the extent, I think, and if so, the reservoir would only fall 5 feet and be at a level of 17·00, which would still supply Black Town and other low parts of the town[3] in which are

[1] Beardmore's formula is $D = \cdot 235 \sqrt[5]{\frac{l \times q^2}{h}}$ in which, D = diameter in feet, l and h the length of pipes and head in feet, and q the quantity to be discharged in cubic feet per second.

[2] Hawkesley's formula is $D = \frac{1}{12}\sqrt[5]{\frac{g^2 l}{h}}$ in which g = number of gallons to be discharged per hour, l the length of pipe in yards, and h the height in feet, and D the diameter of the pipe in inches.

[3] If this plan is adopted, the pipes over the Elephant Gate and Hospital Bridges must be relaid under the canal instead of over the bridge, as they will be too high when this reservoir falls.

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the greater parts of the population. The cost of such a reservoir of masonry may be approximately stated at ₹2,00,000, and if covered, as it should be, it would cost considerably more. It would be unsafe, I think, to put an earthen rivetted embankment so near the town.

Comparison between this scheme and Calcutta.

91. I think it necessary to institute a comparison between the areas of the works allowed in this scheme for settling and filtration—and those at Calcutta, and it is as follows:—

	Scheme for Madras. Square feet.	Calcutta. Square feet.
[1] Settling tanks	270,000	750,000
Filter beds	105,120	160,000

Why area of tanks and filter beds less than at Calcutta.

92. This needs some explanation, and I think it is to be found in this, that the water is so foul above Calcutta where drawn from the Hooghly, that it takes one month to clean a tank, and that the deposit of mud is one cubic inch to the cubic foot, or 1 in 728 in bulk *when dried*. As this, however, has to be removed from the settling tanks in the fluid state of soft mud three or four times daily, the above proportion of bulk amounts to 4,000 to 5,000 cubit feet of mud daily from 6 million gallons of water.[2] Again, in the filter beds two are always available for cleaning at Calcutta; this, however, I think, necessary, looking to the very different quality of water which will be received upon them in this scheme. I have already shown that the area I have allowed is perfectly sufficient, and Calcutta can be no guide in this respect.

93. To give however other evidence. Take the five "Thames Companies," *viz.*, The West Middlesex, Grand Junction, Southwark and Vauxhall, Lambeth, and Chelsea. The average area allowed by these Companies for subsiding reservoirs is 4·22 square yards, and for filters 2·34 square yards per 1,000 gallons in 24 hours; this, for the scheme under consideration, would be—

	Sq. yds.	Sq. feet.
Settling tanks	$\frac{6,000,000 \times 4·22}{1,000} = 25,320$	$= 227,880$
Filter beds	$\frac{6,000,000 \times 2·34}{1,000} = 14,040$	$= 126,360$

Calcutta in excess.

94. It will be seen that the Calcutta area is greatly in excess in both cases. The settling tanks I propose are slightly larger in proportion, while the filter beds are slightly less. It will, however, I think, be admitted that Thames water is never so clear as water from the Red Hills Lake taken from near the surface.

Estimate.

95. In making the estimate I have not gone fully into detail, only sufficiently so to get at a close approximation to the cost. I have allowed ample rates, and having been guided by prices lately paid in the district.

96. The following is my estimate for the works, such as I have detailed in the foregoing reports and on the drawings attached:—

Particulars.	If of brickwork.			If of laterite.		
	R	*a.*	*p.*	*R*	*a.*	*p.*
Construction of tower, including forming dam for it and for culvert	8,000	0	0	8,000	0	0
Machinery in tower	3,500	0	0	3,500	0	0
Pier to support gangway	1,422	0	0	1,422	0	0
Culvert through bund	1,200	0	0	1,200	0	0
Three engines of 32 H. P. nominal including pumps, well, buildings, &c., &c., at 1,200 per H. P.	1,15,200	0	0	1,15,200	0	0
Pumping main between tower and filters, including laying and carting	30,815	0	0	30,815	0	0
Excavation, masonry, drains, puddle, &c., &c., in filters, settling tanks, service reservoir, &c., &c.	5,40,126	0	0	2,65,578	0	0
Turncocks' quarters	3,000	0	0	2,000	0	0
Valve houses at filters (2)	2,000	0	0	1,500	0	0
Offices, stores, &c.	3,000	0	0	2,000	0	0
Gateway	2,000	0	0	1,500	0	0
Sand-washing boxes (2), &c., including piping to do.	1,660	0	0	1,158	0	0
Drains, pipe and tile, &c.	2,000	0	0	2,000	0	0
6·28 miles of 36" main to Madras, including laying and carting an average of 6 miles	4,97,635	0	0	4,97,635	0	0
Stop, self-acting, and air valves, on do.	13,920	0	0	13,920	0	0
Valves, piping, branches, junctions, &c., and machinery at filters	16,644	0	0	16,644	0	0
Total	12,42,122	0	0	9,64,072	0	0
Add for Contingencies, &c., 10 per cent.	1,24,212	0	0	96,408	0	0
Grand Total	13,66,334	0	0	10,60,480	0	0

[1] The depths in this scheme and at Calcutta are the same.

[2] See Jackson on Calcutta Water-Works.

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The above estimate shows the cost of the several works in brickwork and in laterite. The tower which I have shown to be of brickwork in each estimate, might perhaps be also of laterite, but I fear that the latter material is too porous to make satisfactory work in the tower. The difference of the cost of laterite and brickwork is very great. I have estimated that good brickwork can be done at R12 per cubic yard, which is a moderate allowance. Laterite pitching which I propose should be used in settling tanks, and filter is said to have cost at Red Hills Tank annas 8 per cubic yard. I am unable to see how it can have been done for this amount. The price I have estimated these works at is R4 per cubic yard, and this includes plastering with Morgan's cement, and I think there is little doubt that the work can be executed for this amount. It may, then, be safely considered that the cost of these works will not exceed 10½ lakhs, were they to be carried out in full.

Present consumption in Madras.

97. The consumption in Madras at present however is only 7½ gallons per head instead of 15 gallons for which these works are designed. Therefore the full engine power would not be at first required. As the three engines estimated for can do one and-a-half times the work, one engine will do half the work, and if two engines are ordered at present we have one for the contingency of the other breaking down. We may then deduct the cost of one engine, less the cost of buildings, say this is Rupees 1,000 per H. P. nominal, and this decreases the estimate by

H. P. R R

82 × 1,000=82,000.

98. Again, the filter beds will be more than sufficient, and we may do without one of these and one pair of tanks, and this would be about R1,15,000, so that probably the amount required to be at first expended would not be more than R9,00,000.

99. In an Appendix I give the rates at which I have estimated the various classes of work, which will in a measure show whether the estimate is likely to be sufficient or not.

100. There is one method to be noted by which part of the cost of the cartage of piping, engines, &c., might be saved, which is, that most of the material might be landed at the Madras Railway Company's wharf and trucked to Perambore, and thence carted back towards Madras for some distance, and also to the Red Hills; by this means a large saving in the cost of cartage would result.

Maintenance.

101. The cost of maintenance will depend greatly on the cost of coal, which I have put down at R25 per ton delivered at the Red Hills. The monthly cost would probably be as follows:—

		R
1	Superintendent at R250	250
3	Drivers at R60	180
3	Firemen at R20	60
112	Tons coal (4½ lb per actual H. P. (82) per hour at work)	2,800
12	Coolies at R6	72
10	Turncocks R20	200
	Sand for filters and cleaning[1]	550
	Oil, contingencies, &c.	300
	Total	4,412

This is equal to R53,044 per annum. As before shown, the present consumption is only 7½ gallons instead of 15 gallons per head per diem, and the above is for pumping the whole 15 gallons. The cost for the 7½ gallons per head per diem would amount to not more than R30,000 or R36,000 per annum, and this latter amount, capitalized at 5 per cent. = R7,20,000. If we add this amount to the estimate of R9,00,000 it gives us Rupees 97,20,000, which will be the *first total cost.*

102. In concluding this report, I wish to remark that it includes, with the accompanying plans, sections, &c., all the information desired by Government. If the estimate be adopted, and the design for the tower, culverts, &c., be approved by the Chief Engineer for Irrigation, these works may be started at once as pointed out by Colonel Mullins in G. O. under reference. Probably every day now lost will increase their cost.

103. I cannot venture to hope that Government will accept the whole scheme as proposed by me without further professional advice, but I venture to ask that unless some practical objections can be urged against my proposals that they be submitted on any doubtful points for the consideration of some Consulting Engineer of eminence, who might amend the scheme as he considered necessary.

[1] The cleaning of filters has been taken at R2-8 per million gallons filtered in 24 hours. In England it costs about 10*s.* or R5.

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104. No doubt, the scheme might be made more complete, but most probably at increased cost, and if so, I fear that it would be beyond the means of the Municipality to carry out.

105. There is no doubt that the works could be carried out by the Municipality departmentally as far as regards the excavation and masonry works at less cost, and in much less time, and much more satisfactorily than could be done by any contractor, and of this I have had some experience in other places; and I venture respectfully to ask that His Grace the Governor in Council will reconsider his views as to the placing of the works in the hands of an English contractor.

106. I beg that any omissions in this report, these plans, &c., may be criticized as leniently as possible. I have had little or no assistance in their preparation, and it was necessary for me on account of other duties to spend as short a time on this work as possible.

APPENDIX I.

Table showing rates used to form Estimate.

Nos.	Particulars.		Rates.
			R a. p.
1	Brickwork per	Cubic yard .	12 0 0
2	Laterite built in chunam and plastered with Morgan's cement .	Ditto . .	4 0 0
3	Clay puddling	Ditto . .	0 8 0
4	36" Piping delivered in Madras	Ton . . .	80 0 0
5	Laying do. per	Lineal yard .	3 8 0
6	18" Piping delivered in Madras	Ton . .	80 0 0
7	Laying do.	Lineal yard .	2 12 0
8	Cartage of piping per	Ton mile . .	0 3 0
9	Excavation at site of filters, &c.	Cubic yard .	0 4 0
10	Cost of valves, bends, sluices, &c., taken at same rates as Madras W. W. contract.		

APPENDIX II.

The following statement shows the cost of "Gravitation and Pumping" works constructed in England for a supply of 20 gallons per head per day:—

Town.	Population.	Maximum daily supply.	Total Cost.	Cost for a supply of 20 gallons per head per diem.
		Gallons.	£	£
Gosport	22,000	222,000	21,000	1·75
Hartlepool	30,000	2,000,000	75,000	·75
Kendal	13,000	300,000	15,500	1·03
Liverpool	620,000	16,500,000	2,000,000	2·42
The Potteries	130,000	3,000,000	215,157	1·43
Merthyr	55,000	1,500,000	84,000	1·12
Newport	30,000	15,000,000	52,000	0·07

The cost of the scheme now proposed for Madras is, say	. R10,50 000 say	. £1,05,000
It has cost already	. R12,80,000 .	. £1,28,000
	TOTAL	. £2,33,000

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	£
This amount for a population of 400,000 =	0·58 for 15 gallons per head, or, say, for 20 gallons	0·77
The average of the above towns is .	1·37 for 20 gallons per head.
The cost of Calcutta works was £570,596 for 429,535 people=per head	£1·33 for 15 gallons nearly (say) 1·77 for 20 gallons per head.

It will be noted, therefore, that Madras, even after this scheme has been carried out, will be supplied with water at almost half the rate of the English towns noted, and at considerably less than half what the Calcutta works cost.

J. A. JONES.

APPENDIX III.

Memorandum on a method of supplying Madras direct through a pipe without pumping, and by which the water may be able to be drawn when the Lake stands at any level.

I.—The bottom of Red Hills Lake at lowest point is 20·00.

II.—The fall between this level and the point at which the main is joined in the scheme to which this memorandum is attached is 20 feet.

III.—If a continuous pipe be laid to deliver water while the lake is at any level not lower than 22·00, no part of the pipe can be above this level, and none of it should be higher than the line of vertical declivity.

IV.—The distance from the centre of the Red Hills Lake to the point previously described is about 40,820 feet—on a line of country near the present channel, but slightly lower than the level of its bed.

V.—The average depth of cutting required to lay this piping as above described would be 12 feet.

VI.—The means I would provide for drawing off the water would be as follows—

1. An iron cylinder, 8 or 10 feet in diameter, which would be sunk, say, 10 feet below the bottom of the lake, and extend to about 6 feet above full tank level. The total length of this cylinder would be 42 feet.

2. The cylinder would be provided with valves at various depths below the full tank level.

3. The part of the cylinder below the bottom of the tank would be excavated and filled with concrete.

4. The main to Madras would enter through the side of the cylinder, and be turned up through the concrete to the level of the bottom of the tank.

5. There would also be a valve on the main inside the cylinder.

6. The cylinder would be approached by a boat from the banks of the tank.

7. The main must be able to supply at least 6,000,000 gallons per day, but as half of this is drawn off in 6 hours, the main should be large enough to supply 12,000,000 gallons per day, and should be able to do this when the tank is as low as (say) 22·00.

8. The diameter of such a main would be 44 inches.

9. At times when the tank is at a higher level than (22·00) the quantity able to be delivered through such a main would be much increased.

10. The cost of such a scheme as the above is detailed below.

11. I have also shown in a table what a 44-inch and 36-inch diameter main would supply at varying levels of the tank, and the cost of a scheme with a 36-inch main.

12. In starting from the tank it would perhaps be the least expensive method to lay the piping along the channel leading to the Soorapadu Sluice.

13. The iron cylinder would be floated out by means of pontoons, only so much of it being put together at first as would enable it to be lowered to the bottom of the lake without its higher end being covered.[1]

[1] Such a tower as this composed of iron cylinders might probably be cheaper for the scheme with filtration than a brick tower if the tank stood at a high level.

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14. The following are estimates for the above scheme with a 44-inch and a 36-inch main.

	44-inch Main.	36-inch Main.	
			27" diameter.
Cylinder and tower in tank	3,000	3,000	3,000
Erecting do	2,000	2,000	2,000
Machinery in do	2,000	2,000	2,000
Cost of main, lineal yards 13,606[1]	7,61,920	5,71,440	4,44,000
Laying do	68,030	37,416	30,000
Excavation	36,284	31,750	26,000
Cartage of main	10,714	8,035	7,000
Valves in main	8,400	5,760	5,000
	8,90,348	6,61,401	5,19,000
Contingencies	89,052	66,149	51,900
TOTAL	9,79,400	7,27,550	5,70,900

15. The amount of expenditure in maintenance would be very little, certainly not more than what it costs to maintain the present channel.

16. It will be observed that with this scheme there is no filtration, but its advantages over present arrangements would be that water would always be drawn from near the surface of the lake, and that it could be drawn off to a depth of 11 feet below the level of present delivery channel.

17. So long as the water remained above the level of the present channel, the head of water in Madras would be *at least* 2 feet greater than it now is, as there is about 2 feet fall in the length of the channel.

18. A rise in the level of the water in the lake above 31·31 does not practically increase the head to any extent in Madras at present, though it increases the quantity of water which can be delivered by the present channel in a certain time.

19. By means of this scheme the head of water will vary, and when the lake is full the head in Madras will be about 44 feet at the point previously described.

Table showing the quantity of Water which would be delivered in 24 hours by pipes of 44 inches and 36 inches in diameter, at varying levels of the Red Hills Lake.

Tank Level.		Head taken as	Delivered by pipes of		
			44 in. diameter.	36 in. diameter.	27 in. diameter.
Above mean sea	22·00	20	1340 12,060,000	804 7,236,000	398 3,282,000
	27·00	25	1500 13,500,000	900 8,100,000	447 4,023,000
	32·00	30	1640 14,760,000	984 8,856,000	483 4,347,000
	37·00	35	1784 16,056,000	1070 9,630,000	526 4,734,000
	42·00	40	1900 17,100,000	1140 10,260,000	559 5,031,000
	46·00	44	2022 18,198,000	1213 10,917,000	596 5,364,000

NOTE.—The smaller quantities underlined thus—are cubic feet per minute.

The larger quantities are gallons per day.

In reading the above table, it should be remembered that Madras requires 6,000,000 gallons per day, or 666 cubic feet per minute, but that during certain hours the consumption is double this quantity.

J. A. JONES.

[1] Taken as 4,536 pipes, each pipe 2,740lb, R80 per ton (say for 27" pipe 1 thick 5,550 tons).

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APPENDIX IV.

RED HILLS TANK.

Table showing Cubical Contents at half foot vertical intervals.

Height above mean sea-level.	Contents at level in column 1.	Difference of cubical contents at each half foot.	Height above mean sea-level.	Contents at level in column 1.	Difference of cubical contents at each half foot.
1	2	3	1	2	3
Feet.	Cubic Yd.	Cubic Yds.	Feet.	Cubic Yds.	Cubic Yds.
22·31	944,514		34·81	33,646,893	
		541,133			2,108,979
22·81	1,485,647		35·31	35,826,419	
		614,314			2,179,526
23·31	2,099,961		35·81	38,080,312	
		687,191			2,253,893
23·81	2,787,152		36·31	40,406,379	
		759,496			2,326,067
24·31	3,546,648		36·81	42,809,544	
		833,007			2,403,165
24·81	4,379,655		37·31	45,318,050	
		905,787			2,509,506
25·31	5,285,442		37·81	47,899,712	
		962,747			2,581,662
25·81	6,248,189		38·31	50,544,433	
		1,017,892			2,614,721
26·31	7,266,081		38·81	53,248,891	
		1,073,917			2,704,458
26·81	8,339,998		39·31	56,013,395	
		1,127,810			2,764,504
27·31	9,467,808		39·81	58,840,739	
		1,183,244			2,827,344
27·81	10,651,052		40·31	61,767,999	
		1,238,905			2,927,260
28·31	11,889,957		40·81	64,667,822	
		1,251,627			2,900,823
28·81	13,141,584		41·31	67,651,247	
		1,334,328			2,983,425
29·31	14,475,912		41·81	70,716,557	
		1,397,725			3,065,310
29·81	15,874,637		42·31	73,861,778	
		1,464,376			3,145,221
30·31	17,338,013		42·81	77,090,852	
		1,535,388			3,229,074
30·81	18,873,401		43·31	80,401,616	
		1,603,633			3,310,764
31·31	20,477,034		43·81	83,800,897	
		1,655,489			3,399,281
31·81	22,132,523		44·31	87,280,564	
		1,732,440			3,479,667
32·31	23,864,963		44·81	90,838,735	
		1,806,345			3,558,171
32·81	25,671,308		45·31	94,473,127	
		1,881,189			3,634,392
33·31	27,552,497		45·81	98,188,189	
		1,957,987			3,715,062
33·81	29,510,484		46·31	101,981,815	
		2,032,430			3,793,626
34·31	31,542,914				

MEMORANDUM ON MADRAS WATER-WORKS.

Madras depends for its water-supply on two different sources—one being the Seven Wells Water-Works, which supply Fort St. George, the Commissary-General's Office, the Powder Mills, the Shipping and a few other Government buildings, the other being the Madras Water-Works, which is the main supply of the city.

The former supply is worked by Government, and the latter, with which this memorandum deals, is under Municipal control.

The immediate source of the Madras Water-Works supply is the Red Hills Lake.

This lake is, however, fed from the Choleveram lake, and this again from the Kortalayar river, where an anicut has been constructed to divert water from the river into a channel leading to the Choleveram tank.

These tanks lie in a north-westerly direction from Madras, the Red Hills 8 miles and the Choleveram 13 miles. The river is tapped at a point 7½ miles west of the Choleveram tank and 22 miles from the sea.

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The bed of the Kortalayar river at the anicut is 69·30 above the mean sea level. The full tank level of the Choleveram tank is 64·68, and of the Red Hills Tank 46·31, aboye the same datum to which all levels in this report are referred.

The works under the control of this Municipality commence at the south-east corner of the Red Hills tank, where the Municipal sluices and valve house are situated.

The full tank level of the Red Hills tank is, as before stated, 46·31, and portions of the tank bed are as low as 20·00. The lowest Municipal sluice is 31·30.

The tank contains when full 101,981,115 cubic yards, and at a level of 31·31 20,477,034 cubic yards. The total available supply for the Municipality is therefore 81,504,081 cubic yards; but the greater portion of this is used for irrigation purposes, and the amount used during 1879 by the city was only 5,362,185 cubic yards.

The tank for some considerable time during the famine was below the level of 31·31, and pumping had to be resorted to.

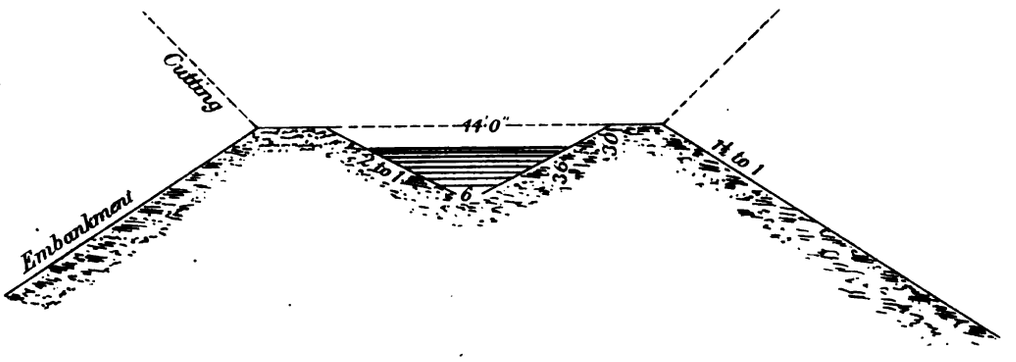
The lower Municipal sluices are below the bed of the tank at the point where they stand, and a channel constructed in the bed conveys the water to them. The sluices are at the following levels:—

No. 1	31·31	There are three pipes at this level.
„ 2	35·31	
„ 3	39·31	
„ 4	43·31	

The water from these sluices is discharged into a basin 80 feet in diameter, which is divided by two parallel walls 6 feet apart. The space between was intended to be filled with charcoal, and thus act as a filter; but as this horizontal filtration proved to have no effect whatever on the water, the filtering medium was removed. The water in this basin is usually at a depth of 2½ feet.

From the basin the water falls over an ordinary shutter weir into the channel now to be described.

The channel, as designed, was of the following section:—



The level of its bottom at its commencement near the basin was to have been 31·31, the same level as the lowest sluice.

It follows a south-easterly course through cuttings and on embankments for six miles and five furlongs.

The gradient proposed for the channel was 3 inches per mile, and the level of the bottom of the channel where it ends at Madras is therefore 29·61.

I have stated above what was the intention, but the works, through faulty construction, were not brought into agreement with the design. The channel bed is irregular, and has a level of 33·00 in some portions. The breadth of the channel also varies, and is in some places considerably below the dimensions given.

The water from the channel at Madras is delivered into a circular well 22 feet in diameter (called the masonry shaft). From this well the main pipes proceed towards the city, the well itself being within Municipal limits.

The depth of water allowed in the channel is 3 feet 6 inches, and the greatest head available therefore at Madras (masonry shaft) is 29·61 + 3·50 = 33·11 feet above mean sea level.

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Sometimes, however, the draught on the main is greater than the amount coming down the channel, and this happens usually between 6 A.M. and 10 A.M. and between 3 and 6 P.M., so that immediately after the earlier of these hours the head rapidly falls, and by noon sometimes there is very little water above the trunk main, which issues from the side of the so-called masonry shaft.

The channel thus acts partially as a reservoir, which gets filled during the night and the midday interval above noted.

There is telegraphic communication between the two ends of this open channel, but when extra water is admitted from the tank it takes 10 hours before it affects the Madras end.

This gives an apparent velocity of 58 feet per minute; but if the amount of water drawn per day be divided by the sectional area of water in the channel, the average velocity is 6 feet per minute, and when the heavy draught is on the channel the velocity will be 24 feet per minute, and at other times the water is being bunded up.

The trunk main which issues from the masonry shaft is 42 inches in diameter and extends for 1,485 yards, from which latter point mains of 36 inches and 30 inches respectively proceed.

An appended table shows the extent of the mains with the valves, &c., attached to each.

The water is supplied to the public through fountains of various descriptions, but these may be classified under—

Cistern fountains.
Wall taps.
Pillar fountains.

The first were adopted with a view to retain a quantity of water should any accident happen to channel or pipes. The cistern fountains have not been a success. They certainly collect a large amount of deposit, but when they are opened for cleaning the smell is unbearable, and all water passing through them must be considerably tainted.

Wall taps are those fixed in walls of buildings, or in masonry built against walls.

Pillar fountains are usually of cast-iron, of a pattern procured from England, and sometimes from part of a lamp-post.

The following are the number of each class of fountains:—

Cistern fountains	42
Wall taps	84
Pillar fountains	113

Large numbers of people who are in the vicinity of water mains take advantage of being so to lead the water into their houses, and the following table shows the rapid increase in the construction of house services, which are paid for by the house-owners, and which cost from ₹50 to ₹200, and in some cases rise to ₹700 each:—

Up to April 1878.	Nine months in 1878.	1879.	First nine months of 1880.	Total.
240	52	136	146	574

Several persons have joined together and paid the total cost of the main in their street, and afterwards paid for the separate branches to their houses. The amounts paid in certain instances have been up to ₹4,000, ₹1,600, and ₹1,000.

Water for non-domestic purposes is charged at 2 annas per 1,000 gallons, and persons are allowed for domestic purposes an amount the cost of which at 4 annas per 1,000 gallons equals the amount paid for water-tax on the property they occupy at the rate of 4 per cent. per annum calculated on the rental.

About ₹1,200 to ₹1,500 yearly is collected for water used for non-domestic purposes.

The original estimate for the works was ₹13,10,000, in addition to which Government made a grant of ₹30,832. The works, however, cost ₹14,30,000.

It would be out of place in a descriptive report to comment on the present state of the water-works. I may, however, report that scour valves are now being put in, which tend to clear the mud from the pipes. The quality of water shows a little improvement. A closed pipe from the Red Hills lake combined with filtration works, if possible, are, in my opinion, works much needed to improve Madras Water-Supply.

J. A. JONES, C.E.,
Vice-President.

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Abstract of Pipes, Valves, Fountains, &c., of the Madras Water Works.

Number of Valves.	Diameter of Pipes.	Lineal Yards of Piping.	Number of Manholes on each size of Pipe.	Number of Fountains on each size of Pipe.	Description of Fountains.												Number of Hydrants on each size of Pipe.	Tyler and Sons.	Ball.	Double Hydrants for Steam Engine.	Number of Scour Pipes on each Main.	Sizes of Scour Pipes on each Main.	Number of Flushing Drain Stand Pipes on each Main.	Sizes of Flushing Drain Stand Pipes on each Main.
					Closed Cistern.	Open Cistern.	Ransom's Patent 4 Tap.	Glenfield's Patent 4 Tap.	Wall Taps.	Stand Pipes.	Lamp Post.	Cattle Trough.	Dip Wells.	Ornamental and Pillar.	Dip Wells for Avenues.	Bathing Fountain.	Drinking.								
	IN.																					FT. IN.		FT. IN.
1	42	1,485	7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	11	11	...	...	...	...	...	...
1	36	1,133	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	...	...	1	0 12	...	...
1	30	866	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	4	...	1	1	0 10	...	...
3	27	3,533	18	2	...	...	...	...	...	...	...	...	...	...	2	...	...	37	37	...	...	3	2 9 1 8	...	...
1	24	1,999	10	1	...	...	1	...	...	...	...	...	...	...	...	...	...	13	12	1	...	2	1 8 1 6	1	0 2
2	22	1,133	5	2	...	...	...	...	...	...	2	...	...	...	...	...	...	14	13	...	1	...	...	...	...
2	21	1,933	9	4	...	...	...	...	...	1	...	...	...	...	3	...	...	19	15	...	4	3	0 7	...	...
1	20	1,166	5	8	...	...	...	...	...	3	...	1	...	...	3	...	1	12	11	...	1	1	0 6	...	...
1	18	2,039	9	2	...	...	...	...	...	...	...	...	...	...	1	1	...	19	15	2	2	1	0 6	...	...
1	16	200	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	...	...	...	...	...	...
1	15	566	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	...	6	1	...	...	...	...
7	14	3,830	12	8	...	2	...	...	...	2	2	...	...	...	2	...	...	24	24	...	...	3	0 6	2	0 1½
9	12	4,861	19	5	...	...	...	...	3	2	...	...	...	...	...	...	...	30	22	8	...	4	0 5	...	...
8	10	1,929	...	1	...	...	...	...	1	...	...	...	...	...	...	...	...	8	8	...	...	...	...	...	...
17	9	4,087	...	8	2	...	...	1	4	...	...	...	...	...	1	...	...	10	7	1	2	...	...	...	...
8	8	1,388	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	...	...	...	...	...	...
																								1 4	
71	7	17,937	...	67	19	3	1	6	23	5	3	...	4	1	1	1	...	54	22	16	16	1	0 4	10	1 2½ 1 1½ 3 1½
35	6	7,418	...	28	6	2	...	4	2	7	2	...	...	3	1	1	...	13	3	8	2	...	...	3	4 1½ 0 1½
16	5	3,194	...	7	2	...	...	2	...	...	1	...	1	1	...	...	...	8	8	...	...	...	...	...	...
98	4	10,211	...	75	5	3	3	30	21	8	...	...	...	3	...	...	2	2	2	...	...	...	...	...	...
7	3	1,588	...	6	...	...	...	...	4	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...
10	2½	1,057	...	9	...	...	...	...	7	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
16	2	551	...	14	...	...	...	1	9	3	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...
6	1½	45	...	1	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
11	1¼	322	...	4	...	...	...	...	...	1	1	...	...	1	...	...	1	...	...	...	...	...	...	...	...
20	1¼	274	...	5	...	...	...	...	3	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
354	...	74,745	107	257	34	10	5	44	77	35	11	2	5	13	14	3	4	293	221	42	30	20	...	16	...

J. A. JONES, C.E.,
Vice-President.

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MONOGRAPH ON THE MADRAS WATER-SUPPLY AND IRRIGATION EXTENSION PROJECT. (1)

CHAPTER I.

Description of the Works as existing.

Madras is supplied with water from a reservoir known as the Red Hills tank, fed by a channel from the River Kortalayar, which passes through a reserve reservoir known as the Cholavaram Tank before it arrives at the Red Hills.

2. The Kortalayar has its origin in the surplus escape of the Kaveripak Tank, which is the principal reservoir fed by the Palar Anicut. It has a length of about 54 miles above the dam which supplies the Red Hills Reservoir, and of about 22 miles below the dam to its outlet into the sea at Ennore, 7 miles to the north of Madras. The area of drainage basin of the river above the anicut, including that of its principal affluent, the Nagari, which receives the Tirutani, is about 1,105 square miles; but 268 square miles of this area have to be excluded, being that of the drainage basin of the Kortalayar above the Kasavaram dam, which is 30 miles above the Thamarapak Anicut. The water coming down the river is almost all taken off at this point and turned into the Kuam River. This leaves 837 square miles as the area actually drained.* The catchment basin consists chiefly of the hilly country forming the Karvetnagar Zemindari in the North Arcot District. This country was formerly well-wooded, but most of the jungles on the slopes of the Nagari Hills have now been cut to furnish firewood for the Madras Railway Company, and as they have not been replanted, the rainfall is said† to have much diminished. The average rainfall on the catchmen, basin may be taken at about 37‡ inches. The river is in flood during the north-east monsoon, and in an average year runs in full flood for four or five days, then with a flow of about 3 feet for thirty or forty days more, when it subsides to the small summer channel, which runs, as a rule, all the year round.

* Mr. Fraser assumed 770 square miles.

† Mr. Fraser's original report.

‡ Averages of five years (1877—81) at the following stations, *vide* sketch map of catchment basin:—

Station	Rainfall. IN.
Tirutani	34·70
Polur	37·86
Thamarapakkam	38·25
Kaveripak	33·40
Kasavaram	41·16
General Average	37·07

3. The dam is built at a place called Thamarapak, where the normal breadth of the river is about 500 feet. The anicut, however, is 624 feet long with the crest at 69·86. The foundations consist of two rows of wells, 6 feet outside diameter and about 6 feet deep, on which rests a depth of 4 feet of solid brickwork.

The body wall is 6 feet high, 6 feet broad at the crest, and 7½ feet broad at the level of the top of the foundations, the latter being on the up-stream side. On the down-stream side there are two aprons—the first, 6 feet below the crest, being 32 feet broad and 4 feet thick; the second at the same level as the first, being 33 feet broad and 2 feet thick. There are eight under-sluices on the south side, each 7 feet × 4 feet, with their sills 6 feet below the crest of the anicut, or at 63·86. The bed-fall of the river averages 3½ feet per mile, and there are embankments on either side up-stream and on the south bank down-stream. The south embankment above the anicut is 2¾ miles long and the north embankment 2 miles long. In section the banks are 4 feet broad at the top, which is 5 feet above F.S.L. in the river, and have side slopes of 1½ to 1. The bank below the river is of similar section, and is 3,900 feet long.

4. The head-sluice to the supply channel has 10 vents, each 5 feet × 5 feet 7 inches, with their sills at the same level as those of the under-sluices. The length of the supply channel from the head-sluice to where it enters the Cholavaram tank is 8 miles 14§ chains. In section it is 30 feet in bottom width, with side slopes of 1½ to 1. The depth of ordinary flow is 2½ feet. The top of the retaining bank on the north side is about 8½ feet above bed-level. The bed-fall of the channel averages 2 feet per mile, and the volume of its discharge at ordinary level is therefore 940‖ cubic feet per second.

§ Of 66 feet.

‖ Kutter's formulæ.

(1) 1. All levels are in feet and decimals, and are referred to mean sea-level, unless the contrary is expressly stated.

2. Volumes are given in cubic feet as a rule, but as, until quite lately, it was usual to state quantities in cubic yards, these have had to be retained in some cases.

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The number and description of the masonry works between the head sluice and the Cholavaram Tank are as follow :—

No.	Description.	Distance from Head.	Level above M.S.L. (1)
		Ms. Chs.	Feet.
1	Inlet, 30 feet long	0 20	75·12
2	Bridge (3 vents of 18 feet)	0 55	62·84 (floor)
3	Outlet, Kattankal surplus weir, 147 feet long	1 60	65·86 (crest) 62·86 (sill)
4	Inlet, 20½ feet long	1 66	67·86
5	Do. 24 do.	2 8	67 24
6	Do. 24 do.	2 39	65·98
7	Do. 20 do.	2 63	64·12
8	Do. 24 do.	2 69	63·40
9	Bridge (3 vents of 18 feet,	3 3	58·30 (floor)
10	Inlet, 24 feet long	3 26	62·81
11	Do. 20 do.	3 44	63·05
12	Do. 20 do.	3 68	63·79
13	Do. 24 do.	4 11	65·23
14	Old Busikal division	4 53	...
15	Outlet, Busikal surplus weir, 141 feet long	4 64	59·69 (crest) 56·69 (sill)
16	Ramapuram Bridge	4 73	56·92
17	Bridge (3 vents of 18 feet)	4 79	54·39
18	Do. (do.)	5 55	53·00
19	Alacheri aqueduct	6 12	52·10

It will be observed that there are ten inlets and two outlets. The Busikal and Kattankal are streams draining 44 square miles and 62 square miles, respectively, and have often breached the supply channel. Estimates for lengthening and improving their outlets have been sanctioned.

5. The total length of the bank of the Cholavaram Tank is 2 miles 22 chains, but the length from where the supply channel enters it to the channel leading to the Red Hills Tank is only 2 miles 5 chains. The top of the bank is 10 feet broad. The inside slope is at 1 to 1 with rough stone revetment and a parapet wall at the top. The outside slope is at 1½ to 1. The F.T.L. is at 61·68, and the area and contents* of the tank at this level are respectively 67·21 million square feet and 766·405 million cubic feet. There are two irrigation sluices. The first, called the north sluice, is at 1 mile from the head of the tank and consists of a vent 3 feet × 4 feet. The head of water over the vent at F.T.L. is 1,985 feet, its level being 41·83. The other sluice is formed by a vent 1 foot × 1½ feet in the body of one of the weirs, 43·84 chains from the head of the tank, with its sill at 52·68; there is also a plug 6 inches in diameter at top and 5 inches at bottom.

* See Chapter IV for fuller details.

There are two weirs. The first is 9 chains from the north end of the tank and 166 feet long, with its crest at 63·62. The second is 43 chains from the same end, 187 feet long, and has its crest at 61·68.

6. The head-sluice to the Red Hills tank supply channel is, as above stated, at 2 miles 5 chains from the north end, and consists of 10 vents, each four feet × 3 feet, with their sills at 45·33 feet. The length of the channel is 2 miles 50 chains to the commencement of the bank of the Red Hills tank; the section of the channel is the same as that of the upper supply channel already described. There is a siphon sluice across the channel at 1 mile 25 chains from the head, and a girder bridge of 40 feet span and floor level 39·76, at 2 miles 29 chains.

7. The Red Hills tank bank begins at the left wing of the north (Mr. Fraser's) weir, and is 3 miles 27 chains long. The section, speaking generally, is the same as that of Cholavaram tank. The top of the bank is at 52·31, and there is a dry stone wall above this raising the level to 55·31 along the deeper parts, and to 54·31 along those of intermediate depth. The full tank level is at 46·31.† The greatest depth of water against the bank is over the sill of the north sluice, where it is 25·65 feet at F.T.L. There are four irrigation sluices and one sluice for the Municipal supply channel in the reservoir.

† Temporarily reduced to 43·31, *vide* paragraph 11, Chapter III.

(1) These levels are referred to de Haviland's B.M. at Madras, which was taken at 6·83 feet above M.S.L. The correct value is now given as 7·83 feet, but the original level has been retained here for convenience of comparison.

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The following particulars refer to the irrigation sluices:—

No.	Distance from Head of Tank.	Level of Sill.	Description.
	Ms. Chs.		
1	15		In surplus weir.
		31·42	One vent 2 feet × 3 feet.
		36·43	Two plugs; one plug, top diameter 7¾ inches, bottom diameter 6¾ inches; other plug, top diameter 8½ inches, bottom diameter 7⅛ inches.
2	32 34		North sluice.
		20·66	One vent 3 feet × 6 feet.
		30·66	Four plugs, upper diameter 10 inches, lower diameter 9 inches.
		40·66	Four do. do.
		21·10	Polal sluice.
3	1 27·07	30·10	Vent as in No. 2.
		40·10	Four plugs do.
4	3 3·25		Soorapedoo sluice.
		27·31	One vent 3 feet × 4 feet.

The Municipal sluice is at 3 miles 15 chains, and contains six pipes of 2¼ diameter each, placed as follows:*—

Three pipes with sill at the level of			31·31
One	do.	do.	35·31
One	do.	do.	39·31
One	do.	do.	43·31

* Proceedings of the Madras Government, No. 1038 W., of April 22nd, 1882.

The reservoir has one surplus weir at the extreme north end, which is 1,401·33 feet long, and has its crest at F.T.L. (46·31). In this weir there is a 10-vented surplus sluice at 21·06 chains, each vent being 6 feet × 6 feet with its sill at 31·31. These sluices, which did not form part of the original design, were deemed † necessary as a safeguard owing to the slips which occurred in the bank of the reservoir after it had been raised. The surplus weir is of ample capacity to discharge all the water to be disposed of, but it does not come into action until the water has risen above F.T.L. It was therefore considered to be desirable to provide means for rapidly lowering the water level, should the bank be in danger of giving way, as also to allow of the discharge of surplus without necessitating the rise of the water level in the reservoir to as great a height above F.T.L. as would be necessary, were all such surplus to be passed over the weir.‡ The area and contents of the reservoir at F.T.L. are respectively 212·103 million square feet and 2,744·8911 million cubic feet. The level of the lowest point of the tank-bed is about 20·00.

† G.O. No. 2322 of August 11th, 1875.

‡ Proceedings, Madras Government, No. 849 I. of December 9th, 1881.

8. The portion of the works outside the Red Hills Reservoir, that is, the Municipal Delivery Channel, are briefly described in Chapter IV, which treats of "The Town Supply of Madras."

CHAPTER II.

Important Phases of its History.

The question of supplying Madras with an abundance of pure water was one that had occupied the attention of Government for many years before the first definite action was taken on the subject in 1866. Numerous reports and suggestions had been submitted by professional Engineers and others, either under the direct orders of Government, or from having their attention directed to the subject by the constant complaints of the gradually increasing impurity of the water drawn from the wells, which then formed the only source of supply.

The reasons for the deterioration in the quality of the well water were not far to seek. Madras being built on the belt of silicious sand which runs along the Coromandel Coast, it followed as a matter of course that a portion of the filth collected on the surface was, owing to the porous nature of the soil, washed down to the water-bearing strata during every monsoon. The Chemical Examiner to Government, who analysed the water of a very large number of wells, reported that the results showed that, with very few exceptions, the drinking water of Madras was as bad as it possibly could be.

2. The first proposal on the subject was made by Lieutenant (now Major-General) O'Connell, R.E., in 1855, who submitted a scheme estimated to cost ₹43,39,476. This

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provided for an anicut across the Kortalayar at Pushali, some distance above the crossing of the Madras Railway and 3 or 4 miles below the Kasavaram dam, which turns some of the Kortalayar water into the Kuam (or Cooum) River. The supply channel, which was to have been about 28 miles in length, was, in its course to the Red Hills, to supply the following eight tanks: Senji, Pudumavalangai, Kadambatúr, Puttalur, Tannirkulam, Pakkam, Palaveda, and Mittanemali. After supplying these tanks, the surplus water for the supply of Madras was to be stored in the Red Hills tank, the bank of which was to be raised 9 feet. An open channel was to convey the water from the tank to two basins in Madras, whence it was to be pumped into settling reservoirs, and passed into the mains for distribution. No detailed plans of this scheme were prepared, and there were, according to Mr. Fraser, two vital objections to it—

(1) that virtually, though not admittedly, it made the storing of water for Madras a matter secondary to that of filling the eight irrigation tanks;

(2) that the supply would have been deficient had the channel been taken from the Kortalayar so close to the Kasavaram dam, which is supposed to turn most of the flood and all the summer water of the Kortalayar into the Kuam for the supply of the Chembrumbaukum and other tanks.

No action was taken on Lieutenant O'Connell's proposals, and nothing further was done till October 1861, when the Municipal Commissioners drew attention to and recommended the substantially similar scheme put forward by Mr. Peter Orr, of Madras. Government, in its Proceedings of December 20th, 1861, referred the subject for the consideration of the Public Works Department, and in May 1862 Mr. Roberts, C.E., was appointed to report on the scheme. But with the exception of one trial line of levels Mr. Roberts confined his observations to the ground previously examined by Lieutenant O'Connell. In 1863, however, Mr. Fraser, C.E., suggested* the possibility of improving upon Lieutenant O'Connell's design, and he was forthwith directed to undertake the re-investigation of the whole project.

* Letter No. 1741 of July 2nd, 1863.

3. Mr. Fraser's first report was submitted with his letter No. 50 of February 26th, 1866, and on 30th April of the same year the Madras Government, when replying to the Budget Orders of the Government of India, intimated† that it was proposed to devote ₹1,10,800 "to the project for the storage of water in the Cholavaram and the Red Hills tank, with a view of increasing the capacity of those reservoirs for irrigation, as well as of providing the city of Madras, its garrison, and public establishments with an abundant and wholesome supply of water, according to the plans and estimates which have been prepared in full detail by Mr. Fraser, C.E., and have recently received‡ the approval of this Government."

† Letter No. 1376 of April 30th, 1866.

‡ In Proceedings, Madras Government, No. 1102, of April 11th, 1866, from which most of the above details have been taken.

4. Mr. Fraser's scheme consisted of—

	₹
I. The construction of a dam across the Kortalayar	30,710
II. The construction of a channel with head and other sluices, and all requisite works from the anicut to Cholavaram tank, a distance of 8½ miles	1,22,055
III. The enlargement of the capacity of this tank by raising its bank 18 feet	1,38,752
IV. The construction of a channel with sluices, bridges, &c., from the Cholavaram to the Red Hills tank, 2¾ miles in length	65,964
V. The enlargement of the capacity of this tank by raising its bank 15 feet	1,17,934
VI. The construction of a channel with its sluices, accommodation bridges, &c., from the Red Hills tank to the Spur tank in Madras	28,032
VII. Sundries, compensation for land and houses, superintendence, &c.	1,33,483
TOTAL	6,36,930

The scheme also contemplated the irrigation of between 8,000 and 9,000 acres of waste land, and it was anticipated that the returns from irrigation alone would suffice to pay a high interest on the estimated outlay.

Sanction to the project was accorded by the Government of India by telegram§ on July 14th, 1866, and by letter‖ on July 19th, 1866, No. 626 C, the total sanction being ₹6,11,759, Item VII of Mr. Fraser's estimate being reduced to—

§ Proceedings, Madras Government, No. 2374, of July 27th, 1866.

‖ Proceedings, Madras Government, No. 3298, of October 16th, 1866.

	₹
Five per cent. for contingencies	25,172
Compensation for land	83,140
TOTAL	1,08,312

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5. In the meantime, however, proposals had been sent to the Secretary of State for the carrying out of the works by a private Company, it being considered* that the financial prospects were so good that funds would be readily forthcoming. The Secretary of State replied in Despatch No. 22 of 1886, dated November 24th. He considered that the promising nature of the work was rather a reason for not seeking the co-operation of a Financial Company, even had there been any probability, which in the then state of the money market was very doubtful, that any Company would be prepared to co-operate. It appeared to the Secretary of State that if Government took upon itself the irrigation part of the scheme, it could thereby render the mere conveyance of water to a reservoir in Madras so profitable a business that it could afford on liberal terms to place the water in the reservoir at the disposal of the Municipality. It would then only remain for the Municipality to construct the distribution works, and if any difficulty were found in raising sufficient funds for that purpose, it appeared that Government would incur little or no risk in advancing the money on the security of water-rates, fixed sufficiently high to be likely to pay off principal and interest within a limited period. The adoption of this plan, besides preventing the water from being made needlessly dear for the profit of strangers, would, the Secretary of State considered, not improbably be beneficial in showing to the Madras Municipality the advantages which they might confer on the town by themselves providing for ordinary municipal requirements.

* Despatch No. 46 of 1866, dated September 13th.

6. The Government of Madras accordingly recommended† to the Secretary of State that the Government of India should be authorised to raise a loan of 8 lakhs to be applied to the construction of the works comprised in Mr. Fraser's project. In reply, it was pointed ‡ out to the Government of Madras that the Government of India had full power to dispose of such questions, and application was therefore made§ to the Government of India to sanction the loan of 8 lakhs. As, however, the requirements of the projects for the year (1867-68) had been stated ‖ to be not more than 3 lakhs, the Government of India appeared to think¶ that the loan was unnecessary and that funds could be provided in the ordinary way.

† Despatch to Secretary of State, No. 7 of 1867, dated February 8th.

‡ Letter from Government of India, No. 40 I., of March 25th, 1867, in Proceedings, Madras Government, No. 1139, of April 13th, 1867; also Despatch from Secretary of State, No. 13, dated April 8th, 1867, in Proceedings, Madras Government, No. 1455, of May 14th, 1867.

§ No. 967 of March 27th, 1867.

‖ Telegram of March 8th, Proceedings, Madras Government No. 696.

¶ Letter No. 40 I.

7. The Municipality, however, required a loan for the construction of the distribution works. Mr. Standish Lee, the then Municipal Engineer, prepared the scheme for these, which were estimated to cost ₹12,80,000, and application was accordingly made** to the Government of India for a loan for this amount.

** Letter No. 3410 of October 30th, 1868.

The Government of India, in replying to the proposal as regards the loan, suggested†† that the Municipality should become joint owners with the Government of the work. The case was stated thus:—

†† No. 55 A.I. of March 11th, 1869, in Proceedings, Madras Government, No. 1014, of March 24th, 1869.

"The whole additional supply of water stored is 2,700 millions‡‡ cubic feet; of this 1,431 millions are to be used by the Government and 864 millions by the Municipality, besides 405 millions which are of no use; in all, the Municipality has 1,269 million cubic feet stored for its purposes. If therefore, the cost (8 lakhs) be divided in the proportion of 53 to 47 (1,431 to 1,269), it gives 4¼ lakhs for Government and 3¾ lakhs for the Municipality; it is then proposed that the Municipality shall be considered as joint proprietors of the reservoirs, and be allowed to pay the interest on the above capital, *plus* a proportional share of maintenance charge."

‡‡ Stated in cubic yards in original.

The Municipality declined,§§ however, to accept the offer of joint proprietorship, and the loan of ₹12,80,000 was sanctioned‖‖ by the Government of India on the terms originally proposed by the Madras Government, *viz.*, at 6 per cent. per annum, 4 per cent. to be considered as interest for the money and 2 per cent. to be credited to a sinking fund for the liquidation of the debt, the Municipality being further required to pay ₹1 per 27,000 cubic feet for the supply of water received from the reservoirs. This latter point was strongly insisted¶¶ on. "The Municipality has elected to be treated as a customer in respect to the water supplied, and it cannot therefore reasonably hope to enjoy more favourable terms than those granted to the public generally. The Governor-General in Council, moreover, requests that it may be distinctly pointed out to the Municipality that the free use of water from the Government reservoirs must not be looked for."

§§ Proceedings, Madras Government, No. 1622, of May 17th, 1869.

‖‖ Proceedings, No. 126 A.I., of June 25th, 1869, in Proceedings, Madras Government, No. 2327, of July 17th, 1869.

¶¶ Government of India Resolution, No. 126 A.I., of June 25th, 1869.

8. As the works in connection with the storage progressed, it became evident that the original estimate for them would prove wholly insufficient, and a revised estimate, amounting

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to Rs. 10,42,640, is noticed in Proceedings, Madras Government, No. 1100, of April 26th, 1870. This, however, was not forwarded to the Government of India, as doubts had been thrown on the estimated returns from irrigation, and it was considered advisable that a definitive decision should be come to on this point before any revised estimate was submitted for sanction. But as it was not possible to delay the progress of the works, the outlay soon largely exceeded the sanction, and the revised estimates were repeatedly called* for. Not being ready, the Government of India ruled† that all expenditure after January 1st, 1871, should be debited to the Ordinary Agricultural grant instead of to the Extraordinary (Loan Funds) grant, from which the previous expenditure had been met.

* Proceedings, Madras Government, No. 2697, of November 10th, 1870. Proceedings, Madras Government, No. 2909, of December 2nd, 1870.

† Proceedings, Madras Government, No. 233, of January 26th, 1871. Proceedings, Madras Government, No. 520, of February 21st, 1871.

9. The Madras Government eventually decided‡ that a Committee should be appointed to report on—

‡ Proceedings, Madras Government, No. 939, of May 29th, 1871.

(1) the complete outlay required in order to place the works in a satisfactory condition;

(2) the total return to be equitably credited to the works;

(3) the charge for maintenance.

The Committee's Report§ is dated July 14th, 1871, and was forwarded to the Government of India with letter No. 2172 of August 23rd, 1871. It is therein stated that the estimated total cost had risen to Rs. 12,25,558, owing to—

Proceedings, Madras Government, No. 2171, of August 23rd, 1871.

(1) increased rates;
(2) improvements in design;
(3) additional rates;
(4) increase in land compensation.

The estimated return had also fallen from Rs. 1,12,166, at which it was taken in 1870, to Rs. 49,000. It was suggested that the portion of the expenditure on which this return would pay 6 per cent., or Rs. 8,16,666, should be met from Loan Funds, leaving the balance, Rs. 4,08,892, to be defrayed from Ordinary.

10. The Government of India did not, however, approve of the latter part of this proposal, considering‖ it to be unfair to tax the public in the Madras Presidency generally with one-third of the cost of a project undertaken principally on behalf of the city of Madras, and for which there seemed no doubt the city could well afford to pay. An enhancement of the price to be paid for the water by the Municipality was therefore recommended. It was pointed out that in Calcutta only about 2,440 gallons of water were obtained per rupee, and in Bombay only about 8,000 gallons, against 168,750 gallons per rupee, which would be the rate in Madras. In reply to this the Government of Madras pointed¶ out that a distinct engagement had been made with the Municipality not to charge more than Rs. 32,000 per annum for the water, on which understanding it had declined** to become a joint proprietor, and that, moreover, the cost of supply should be estimated on the volume used, not on that available. In regard to this it was said that the supply was not expected to reach more than 312,000†† inhabitants, and even assuming that each person took as much as 20 gallons a day, this would only give a yearly consumption of 2,277 million gallons, or at the rate of 16,824 gallons per rupee.

‖ Letter No. 695 I., of November 10th, 1871, in Proceedings, Madras Government, No. 65, of January 10th, 1872.

32 million cubic yards = 5,400 million gallons for Rs. 32,000.

¶ Letter No. 1015 of April 18th, 1872.

** Letter No. 1015, of April 18th, 1872.

†† Out of a population of 397,000, the census of 1871 showed that the supposed population of Madras was very much larger than proved to be the case.

11. The Government of India accepted this reasoning, and with letter No. 05 I.‡‡ of May 10th, 1872, forwarded a copy of a letter it had addressed to the Secretary of State recommending that the proposal should be adopted that 8 lakhs of the expenditure should be met from Loan Funds, and the balance from the same source in the first instance, but to be repaid by annual instalments of 1 lakh, one-half of each instalment being met from the Ordinary grants to the Madras Government for Agricultural Works, and the other by a reduction of the Provincial Assignments to that extent.

‡‡ Proceedings, Madras Government, No. 1452, of June 12th, 1872.

12. The Secretary of State did not, however, approve of this proposal. In his despatch§§ No. 59, of July 10th, 1873, after reviewing the circumstances of the case, he said he regretted he could not concur as to the mode in which the difficulty should be met it being entirely opposed to the policy under which expenditure on remunerative works was

§§ Proceedings, Madras Government, No. 162 B., of January 24th, 1874.

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permitted to be undertaken from borrowed money, that any portion of the cost of a work which is shown to be unremunerative should be debited against Loan Funds. It was therefore ordered that no part of the principal or interest of the money laid out should be eventually debited to Extraordinary Funds.

13. The Government of India, in forwarding a copy of this letter from the Secretary of State to the Government of Madras, remarked that the Accountant-General, Public Works Department, had reported that the ultimate expenditure was likely to amount to more than 15 lakhs, instead of Rs. 12,25,558 as reported by the Committee of 1871, owing to no provision having been made in the estimate for establishment and tools and plant charges. The actual outlay to the end of 1872-73, combined with the grant for 1873-74, showed the following results :—

No. 854 I., of December 9th, 1873, in Proceedings, Madras Government, as above.

	Loan Funds.	Ordinary.	Total.
	Rs.	Rs.	Rs.
Works	8,45,616	3,71,989	12,17,605
Establishment	1,64,231	1,05,045	2,69,276
Tools and plant	7,901	9,123	17,024
TOTAL .	10,17,748	4,86,157	15,03,905

The refund to be made accordingly amounted to Rs. 10,17,748, and, with a view of affording every assistance in its power to the Government of Madras, the Government of India authorised the Accountant-General, Public Works Department, to debit the Ordinary and credit the Extraordinary grant with Rs. 5,70,000 in the accounts for 1872-73 for the Madras Water Supply Project. This left Rs. 4,47,748 still to be refunded, which it was suggested should be done in the following way : 2 lakhs from Provincial Funds by annual amounts of Rs. 50,000, commencing from 1874-75, and the balance in three instalments from the Ordinary grant under Agricultural. Subsequently all Irrigation works, including Agricultural, were included under Imperial, and the refund had therefore to be made entirely from Provincial. It has been carried out in the following* way :—

* Proceedings, Madras Government, No. 849 I., of December 9th, 1881.

	R
By transfer in 1876-77	50,000
Do. in 1878-79	50,000
Do. in 1879-80	1,00,000
Do. in 1880-81	1,00,000
Do. in 1881-82	1,00,000
Do. in 1882-83	47,748[1]
TOTAL .	4,47,748

14. But this does not constitute the whole refund. The estimate, amounting to R12,25,558, sanctioned in Government of India letter No. 695 I, of 10th November 1881, only included works and petty establishment charges, the regular establishment charges, and those for tools and plant having been omitted, as well as all indirect charges. It was found also that several of the component works required extension or modification, so that an additional provision under works was necessary, and a revised estimate to include all these additions was called for. Great delay occurred in submitting it, and it was not till the 9th of December 1881 that the revised estimate was forwarded for the sanction of the Government of India. It amounted to R18,54,463, divided thus :—

Proceedings, Madras Government, No. 849 I.

	R
1. Anicut and head works	95,839
2. Cholavaram Tank supply channel	2,45,670
3. Cholavaram Tank	2,67,367
4. Red Hills Tank supply channel	1,32,882
5. Red Hills Tank	2,98,609
6. Distribution	27,201
7. Land other than for the Madras Municipality	1,45,079
8. Miscellaneous	58,596
9. Items chargeable to Provincial	96,573
	13,67,816
Deduct amount charged to works, which belongs to establishment .	24,866

[1] Entry in Budget for 1882-83.

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	R
Total Works	13,42,950
Establishment	2,19,255
Tools and plant	8,201
	15,70,406
Less Receipts on Capital Account	1,167
Total Direct Charges	15,69,239
Capitalised Abatement of Land Revenue	2,13,320
Interest	71,904
GRAND TOTAL, DIRECT AND INDIRECT	18,54,463

The total of this estimate is divided as follows :—

	R
Imperial	9,82,105
Provincial	8,72,358

so that the whole of the charges having been originally met from Imperial, and only ₹4,47,748, as above stated, added to ₹23,214 originally met from Provincial, having been refunded of the Provincial share, there is still a refund of ₹4,01,396 to be made. This, it has been ordered,* is to be carried out in the Civil Accounts, by continuing to refund one lakh year by year, including 1882-83, until the whole debt has been paid.

* Letter from Government of India, No. 228 A-G, of 5th June 1882.

CHAPTER III.

ACCOUNT OF THE ENGINEERING DIFFICULTIES ENCOUNTERED, AND OF THE MANNER IN WHICH THEY WERE OVERCOME.

The project has suffered from its commencement to quite an unusual extent, both from the accidents owing to floods of unexpected severity to which every irrigation work is liable, and also from mistakes made in the original method of execution, the two reservoirs comprised in the project being formed by additions to old works, and requiring therefore exceptionally careful treatment, which unfortunately they did not receive, to ensure homogenity between the old work and the new. The difficulties arising from these two causes will be taken separately.

I.—DAMAGES FROM FLOOD.

2. In October 1870 a very heavy flood came down the Kortalayar, the water rising to 16 feet above the sluice sill, or 10 feet above the crest of the anicut, and 4 feet above the flood-level as originally estimated. The anicut was but slightly damaged, but the up-stream wings of the head sluice were carried away, and a large breach was formed behind them. The roadway of the head sluice, being only 15 feet above the level of the sluice sills, was 1 foot under water. The supply channel from the river was also breached in several places by the land drainage brought into the channel by the two streams called the Kattankal and Busikal, the existing works being insufficient to pass the discharge across the channel.†

† Proceedings, Madras Government, No. 2774, of 18th November 1870.

3. In November 1882 a still higher flood occurred, the water rising to 13 feet above the crest of the anicut, and also over the banks on both sides of the river Kortalayar. The flood turned the north wing of the anicut, and breached extensively the south flood-bank above it, causing, in consequence, considerable damage to the supply channel. The anicut itself sustained no injury, but a small portion of the wing-wall which was turned was carried away. The breaching of the south flood-bank let a large volume of water into the country beyond, which found its way into the Kattankal and Busikal, thence into the supply channel, which was breached, and so back to the Kortalayar. The additional works which the flood showed to be necessary consisted of—

(1) Lengthening the anicut by 150 feet, making it 624 feet long. The estimate for this amounted to ₹25,000.‡

‡ Proceedings, Madras Government, No. 2132, of 26th August 1873. The actual cost was ₹23,437.

(2) A further raising of the roadway of the head sluice to the supply channel, which had only been 6 inches above the flood of November 1872. The necessary raising was recommended,§ to be effected by closing the spaces between the piers which carry the shutter gear,

§ Proceedings, Madras Government, No. 2132, of 26th August 1873.

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and by raising the earthworks at either end to the level of the tops of the parapets of the wings.

(3) Raising the flood-banks on each side above the anicut and on the south side below it. The banks above were raised to 5 feet above the level of the 1872 flood, that on the south side having its terminus on the Veliyur Tank bank, and that on the north side on a village boundary mark. Below the anicut on the south bank there was a flood embankment extending three-fourths of a mile to comparatively high ground, but the upper part of this bank was much too low. The flood-level below the anicut reached 80·83, or 2 03 below that above the dam. At 10,300 feet, or rather less than 2 miles, its level was 76·96, so that the surface fall was 1·97 feet per mile, and to the proposed terminus of this bank, a length of 3,900 feet, the fall would be 1·46 feet, making the flood-level here 79·37. The ground here was at 81·32, giving a margin of 1·51 feet, but on the whole it was considered* safer to make the bank here, 8 feet higher or, say, 84·31. This high ground had to be connected with the left bank of the supply channel, as in 1872† the water in the Kortalayar had risen considerably above the level of the crests of the then existing weirs. The level of the top of this connecting bank was also fixed at 84·31 feet. The estimates for these banks were—

* Proceedings, Madras Government, No. 1222 of May 7th, 1874.

† Proceedings, Madras Government, No. 2132 of August 26th, 1873.

	R
Flood-bank north of Kortalayar above anicut	5,550
Do. south do. above and below anicut	6,800

and were sanctioned in G.O. No. 1222 of 7th May 1874.

4. In October 1874 a higher flood even than that of 1872 occurred in the Kortalayar, the levels of the water in each case being given‡ as—

‡ Proceedings, Madras Government, No. 2011, of July 15th, 1875.

	1873.	1874.	Difference.
At 1 mile 1,293 yards above anicut	87·32	90·85	3·53
Anicut	82·86	84·20	1·34

The embankments above the anicut were not much damaged, only three small breaches which perhaps were intentionally caused by the villagers, having been made in the south bank; but it was discovered that the terminus of this bank did not fulfil its purpose, as it proved capable of being turned. Estimates amounting to R2,558 for completing the right flood-bank, and to R4,900 for extending it, were sanctioned in G.O. No. 368 I. of 3rd October 1877. The anicut suffered more than the embankment, but principally from local scour. The foundations of the crest wall were undermined for a length of about 120 feet, the front row of wells disappearing almost entirely, and the second row settling considerably. The crest wall went out of the upright, parts of it also being carried away, and a crack appeared in the rear apron. The remedy proposed,§ besides the restoration of the damaged portion, was to lay an apron of rough stone 21 feet wide and 2 feet thick at a gentle slope on the up-stream side of the crest. The supply channel was also damaged, owing to the impossibility of discharging through it when the Kortalayar is in high flood, all the land drainage coming into it. The drainage basin of the Kattankal is estimated at 62|| square miles and that of the Busikal at 44 square miles, and it was calculated that allowing M.W.L. in the channel to be 10½ feet above the bed or 4½ feet above F.S.L., weirs of 280 feet and 216 feet in length, respectively, would be required to discharge the drainages. This was supposing the weirs to have flush crests, but by adopting self-acting revolving shutters for the vents the lengths were reduced to 144 feet and 135 feet, respectively, and estimates for these improvements, amounting to R18,400,¶ for the Kattankal escape and to R16,900** for the Busikal escape were sanctioned in G.O. No. 2785 of 17th October 1876. Their execution had, however, to be deferred pending the sanction of the revised estimates. The proposed arrangements, even when carried out, do not promise to be wholly satisfactory, but it is impossible to devise adequate arrangements at a reasonable cost. Should the river be in extreme fresh when the local rainfall approaches a maximum, the discharge of the drainages cannot be disposed of without exceeding the proposed M.W.L. in the channel, and on the rare occasions when these unfavourable circumstances may combine, the left bank of the channel will probably breach at points which will be left exceptionally low so as to fix the site of the breaches.††

§ Proceedings, Madras Government, No. 2011 of 15th July 1875.

|| Proceedings, Madras Government, No. 2785 of 17th October 1876.

¶ Subsequently increased to R19,000.

** Do. do. R17,400.

†† Proceedings, Madras Government, No. 849 I. of 9th December 1881.

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5. An estimate, amounting to ₹2,135, for raising the connecting bank between the flood-bank of the Kortalayar below the anicut and the bank of the supply channel, the necessity for which had been shown by the same floods of 1874, was sanctioned in G.O. No. 368 I. of 3rd October 1877. The condition of the river embankments, of the anicut, and of the supply channel was generally satisfactory on the occasion of the inspection of the works by the Chief Engineer for Irrigation in November 1881.

II.—Damages to the Reservoirs.

(1) *Red Hills Tank.*

6. In February 1870 leakage was first noticed in the bank of the Red Hills tank near the north end, when only 4½ feet depth of water above the old Calingulah crest had been admitted to the tank out of the additional depth of 15 feet which it was designed to hold. The leakage was considerable for a length of 867 feet, and for an additional length of 4,596 feet the water passed through or under the bank in smaller quantity. The new earthw ork which had been placed on the top of the old bank had, it was supposed, been rendered im permeable by means of a puddle wall, but it appears to have been taken for granted that the old earthwork below this puddle wall would also be impermeable even under the pressure due to the increased depth of water. In those portions which were composed of clay soil no leakage took place, but under certain portions of the embankment laterite gravel and rock crops up, and there the water found its way through. The remedies proposed and carried out were—

(1) At 5 or 6 feet from the foot of the revetment a trench from 8 to 9 feet wide was carried down to a little below the original ground surface and filled in with puddle. The soil between this puddle and the revetment was then removed to a depth of 4 feet in short lengths at a time, and also filled in with puddle, the whole of the excavated earth being then placed over the puddle, well-watered and rammed. The cost of this was estimated at ₹14,595.

(2) Low retaining walls were built at the foot of the rear slope where the leakage was heavy to prevent slips. The cost of this was ₹1,905.

Proceedings, Madras Government, No. 1959 of 17th August 1870.

7. In November 1871 about 178 feet of the bank of the Red Hills tank settled slightly, owing, it was supposed, to heavy rain having sunk down to the new earth in the rear of the puddle wall. The settlement was slight and no danger was apprehended.

Proceedings, Madras Government, No. 72 of 11th January 1872.

8. In October 1872 another settlement occurred* in precisely the same spot, the maximum subsidence being 0·95 of a foot. Exaggerated reports as to the subsidence were current in Madras and excited some alarm, but the Chief Engineer for Irrigation reported (1) that the tank was in no danger of breaching, and that (2) even did it breach, the water would not inundate Madras, but would find its way into the Ennore backwater, some 5 miles to the north of the city. Certain remedial measures were proposed, but before they could be completely carried out very heavy rain again fell and the bank again slipped on October 14th to 18th in the same place. This time the slip was more serious, and the sinking consequently greater. A length of 437 feet was disturbed, the depression being greatest at the two ends, where it was 2·11 feet and 1·41 feet on the north and south sides respectively. The slip was attributed to the use of clay with a large admixture of inferior yellow soapy soil for the bank, together with the absence of a gravel backing that should have been provided to the revetment. A searching enquiry was ordered in Proceedings, Madras Government, No. 3014 of December 18th, 1872, the results of which are given in Proceedings, Madras Government, No. 1926 of August 1st, 1873. A note by Major Scott, R.E., who had been in charge of the works for many years during their construction, is printed therein, which throws much valuable light on the causes of failure. The new work having been raised on the old bank, obviously hung on an inclined plane represented by the back slope of the old bank, so that when the new work settled on being permeated by water under pressure, the old work did not participate in the movement, and dislocation therefore took place, the line of fracture being along the back slope of the old bank. The failures were favoured by the slippery blue clay which formed the lower part of the backing, as the water would naturally have a tendency to travel along the line of junction of the old and new works, especially if assisted in its passage by the remains of roots of trees, grass, or vegetable soil. Dislocation having once taken place in this way, it is easy to see that the addition of earth to make up the bank to its proper level would, by adding to the weight of the mass in a state of unstable equilibrium, tend to renew the slide downwards. This is what actually occurred, the bank continuing to sink as fast as earth was added. The slips were due

* Proceedings, Madras Government, No. 2466 of 19th October 1872.

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partly to an error in design, and partly to errors in execution. It would have been preferable to provide for the additions to the bank being made on the inner instead of on the outer slope, as the pressure of water would then have held the new earthwork against the old bank. But even if this were not done, as in the case of the work as executed, failure might have been guarded against had the old bank been thoroughly cleared and broken up to ensure junction with the soil added.

9. On 2nd December 1873, another and very extensive slip occurred,* 1,600 feet north of the Polal sluice, or about half way between it and the slips of the previous year, very heavy rain having fallen during the previous few days and saturated the bank. A quantity of what was described as "utter boggy stuff," which had been covered by sound earth, was exposed. The remedial measures adopted were similar to those previously ordered, *viz.*, the drainage of the fallen mass so as to form a sort of retaining bank, and the re-formation of the bank with sound earth.

* Proceedings, Madras Government, No. 238 of 2nd February 1874.

10. The bank stood well during the heavy rains of October 1874, and was not subjected to any further severe test till 1877, when, on 17th November, a slip again occurred, due† to the saturation of the lower part of the rear of the bund, resulting from the porous laterite sub-soil. The drainage of the bank where the slip took place was again ordered.

† Proceedings, Madras Government, No. 38 I. of 14th January 1878.

The new sluices in the waste weir failed‡ on the same occasion, owing to water working under the covering stones of the vents and forcing them up by hydrostatic pressure. The insertion of these sluices for the purpose noticed in the 7th paragraph of Chapter I had been sanctioned in Proceedings, Madras Government, No. 2322 of 11th August 1875, at an estimated cost of ₹17,100. It was discovered in 1877 that the concrete foundations on which the piers of the vents stood had to a great extent been washed out, having been made of bad material. When the floods had subsided, a coffer-dam of earth was put round the sluice-vents, pending the preparation of the estimate for all the repairs the tank was held to require.

‡ Proceedings, Madras Government, No. 38 I. of 14th January 1878.

11. In May 1879, however, a cyclonic storm passed over Madras, the fall of rain being very heavy, with the result that a portion of the coffer-dam was washed away. The breach was with difficulty closed. In passing orders on the papers reporting this occurrence, Government signified a desire§ to have complete information on the following points before deciding what further work should be undertaken for the security of the reservoir:—

§ Proceedings, Madras Government, No. 374 I. of 1st July 1879.

(1) The cost of draining the rear portion of the bank which had been reported by the Chief Engineer for Irrigation in September 1878 to be still saturated with moisture for a considerable distance.

(2) The cost of raising the parapet wall of the tank. The top of the bank referred to M.S.L. is 52·31, but there was a dwarf parapet wall of laterite stone at the top of the revetment which made the margin above F.T.L. nearly 7 feet. It was considered that it would add considerably to the safety of the reservoir to raise this parapet to 55·31 along the deeper parts of the tank, and to 54·31 along those parts which are of intermediate depth.

(3) The cost of repairing the surplus sluices in the waste weir of the tank.

(4) The cost of rendering the tank bank completely secure from the right wing of the surplus weir to the end of the apparent leakage, a short distance south of the Polal sluice, by the insertion of a puddle core wall in the bank, with a longitudinal drain at the back of the puddle wall, and cross drains to the rear toe of the bund at intervals of from 50 to 75 feet according to the amount of leakage manifested.

Until this information had been furnished, it was directed that the surplus sluices should be left unrepaired, and the surplus weir kept at its then level of 43·31,‖ water being retained as near to the F.T.L. of 46·31 as circumstances might indicate to be prudent by means of temporary arrangements, as had been done since the first failure of the sluices in 1877.

‖ The crest of the weir had been lowered temporarily to 43 31 in November 1877.

12. The preparation of the estimates required by Government, as mentioned above, involved borings being made in the bank, and these confirmed the previous evidence of the very mixed character of the material used in the formation of the embankment, and showed, moreover, that the old as well as the new portion was constructed in a very unreliable manner. In two of the borings water was met with at 22 feet from the top of the bank or at 14 and 12 feet, respectively, below the actual water level, and in one bore hole the water rose to about 6 inches below the water level, indicating a very unsafe freedom of communication between the water in the tank¶ and the interior of the bank. This proved very conclusively that a puddle core wall could not be inserted in

¶ Proceedings, Madras Government, No. 406 I. of 24th June 1880.

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the bank without first lowering the water level in the tank considerably. Nor did it appear at all certain that the insertion of a puddle wall would be sufficient to stop the leakage. Its effect would be to cut off all but sub-soil leakage from the bank behind it, and such leakage might, it was evident, be disposed of by means of drains. But the front part of the bank would still remain in its then condition, *i.e.*, in some parts of the consistency of batter, and settlements might therefore take place at any time which would involve the rupture of the puddle wall and admit water to the rear part of the bank. It seemed, therefore, that nothing less than the formation of a properly-constructed bank inside the existing bank at the places where the latter was rotten could render the tank secure, and to carry this out, it would have been necessary to empty the tank and to keep it empty for many months. But to do so, and by so doing to cut off the supply of water to the city of Madras, was out of the question, even had the necessary supply of material been forthcoming, which was not at all certain.

Whatever remedial measures might be ultimately adopted, it was certain, however, that transverse drains under the unstable portion of the bank would have to be inserted, and in view of the above-mentioned difficulties, it seemed advisable to see first what would be the effect of these. It was considered possible that they would so far induce consolidation of the bank as to allow of a connecting longitudinal dry stone wall being inserted on the line of the inner ends of the drains, which would have the effect of securing freedom from water to all the rear part of the bank and to ensure its stability. The result would then be a front part of the bank not much, if at all, altered in condition, and a rear part so arranged as to afford the front part adequate support; between this support in rear and the water pressure in front, practical stability might be found to exist.

13. In accordance with the above recommendations, the following estimates were sanctioned in Proceedings Madras Government, No. 406 I. of June 24th, 1880 :—

	R
(1) Parallel drain in rear of south part of bank	90
(2) Fifty transverse drains in bank	6,000
(3) Longitudinal drain and dry stone wall	8,200
(4) Channel to lower the water-level of pool in rear of bank to 21·00	300
TOTAL	14,590

14. The following is a copy of the specification for carrying out the above works :—

"*Transverse drains.*—These drains will start at the level of 21·00, at which level the sole of the drains at their outfall will throughout be fixed at all places at which there is a pool or lower ground in rear of the bund. Where the ground level is higher than 21·00, a drain parallel to the bund will be cut along low ground not less than 30 feet from the toe of the rear slope with a fall of 1 foot* in 10 chains starting with the level of 21·00 at the lower end. The head of this drain to have a width of bottom of 1 foot and side slopes of 1 to 1. The bottom width to increase by 6, inches at the end of every 10 chains, *i.e.*, at 10 chains from the head it will be 1½ feet wide, at 20 chains 2 feet wide, and so on. The soles of the transverse drains at their outfall will be 0·50 foot above the bottom of the parallel drain. All open transverse drains to have a fall of 1 in 330.

* 8 feet a mile.

"All drains filled with stone to have a fall of 1 in 30. The transverse drains under the bund to be run into a line 22½ feet from the rear face of the bund parapet. As the lengths and starting levels of these drains will vary, so will the sole level at the inner end.

"2. *Excavations for transverse drains.*—These drains outside the toe of the bund to be 1½ feet wide at bottom with side slopes of 1 to 1.

"The cuttings into the bund to be at right angles to its alignment, and to be 3 feet wide. Taking the rear slope as on the average 2 to 1, the cutting will be about 3 feet deep at 6 feet deep from its commencement, and, so far, the sides may be left unsupported. All the cutting beyond this to be supported by close planking with struts or distance pieces at 6 feet apart horizontally or in the direction of the length of the plank, and vertically according to circumstances.

"The simplest arrangement will be to lay the planks parallel to the sole of the drain. As soon as about 30 feet in length of the cutting for a drain has been completed down to sole level, the stone for the drain should be laid in and handpacked. This stone should be in irregular roundish lumps, 4 to 6 inches in diameter. Turf sods should be laid vertically at the sides, with the grass next the stone, and on removing the planks the space left vacant should be filled in with good soil well-tamped. The stone to be covered in with turf sods, grass downwards, and the bund re-formed to section, the planks being removed one by one as the filling in progresses; the soil to be carefully tamped in 3 or 4 inch layers. The stone at the end of each length of drain thus formed to be protected from being obstructed by the earth by a plank placed vertically against the stone and edge of turf; this plank will be removed when the next length of stone is about to be laid down.

"Should much water be met with as the cutting progresses, the drain should be laid in with stone, and the bund re-formed over it in shorter lengths, say of 10 feet, so as not to leave any greater length open at one time than can be quickly closed and completed, should the adjacent soil show signs of being washed out by the water. The width of the cutting being only 3 feet, it is probable that the face of the bund at its end, which may be cut at a slope of ¼ to 1, will stand without support, but preparations must be made for supporting it by short pieces of plank, with cleats fastened to the side planking if necessary. All the planks will be 2 inches thick, so these planks for the face should be 2 feet 7½ inches long, and wedges should be driven between the ends, and the side planking to hold the short planks until the cleats have been fixed.

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"3. *Longitudinal dry stone wall.*—On the completion of cutting for a transverse drain, it will be seen what the nature of the bund at this point is, as also whether water finds its way through only at the bottom or at points above the level of the drain. It will then be determined whether a longitudinal dry stone wall is to be inserted or not. If this be ordered, the excavations for it will be made in lengths of 10 or 12 feet at a time, on either side of the head of the transverse drain, commencing from the top of the bund, with a lining of close planking on either side of the trench and struts. The trench to be 3 feet wide down to the level of the surface of the natural soil or ground level, below which a width of 2 feet will suffice. The bottom of the wall to be laid at 23·00, except where original ground level is reached at a higher level, in which case it will be not less than 2 feet below ground level, the exact depth being determined from the nature of the soil, which, if porous, will necessitate excavation being carried lower. The wall will be in some cases founded lower than the head of the transverse drain. The dry stone wall will not be a necessity where the bund above the level of the transverse drain is water-tight and its height may be according to circumstances, *viz.*, to the level at which the bund is good and water-tight. It may therefore be anything from the 2 feet of a simple longitudinal drain to that which would approximate to F. T. L. Generally it may be considered unlikely that it will need to be carried much above the surface of the old bund, but in all cases it should cut off from the bund in rear all water passages, so that the rear of the bund may be left dry and stable.

"4. *Order of execution of work.*—The longitudinal open drain in rear of the bund must be completed before the transverse drains having an outfall thereinto are commenced. The transverse drains into the bund must be formed before a longitudinal drain or a longitudinal dry stone wall is put in, because the transverse drains are required to carry off all water tapped or met with in excavating for the L drain or dry stone wall. The excavations for these latter are to be so arranged as to afford uninterrupted drainage to the transverse drains on either side. Care to be taken that the heads of the transverse drains are not choked by silt from the excavations.

"5. *Drainage of pool in rear of bund.*—Arrangements are to be made by an outfall channel to keep the water-level down to 21·00 as a maximum, and to this end the sole of the outfall channel at its head must not be higher than 20·50, and it may have to be lower. On the plan (tracing), dated 2nd September 1879, of the tank there is a drainage from the pool marked, but there is nothing to indicate that it is effective, and it is not shown as running into any channel which would carry the water away."

15. A report regarding the works as executed is contained in Proceedings, Madras Government, No. 307 I. of May 10th, 1881. From these it appears that 50 transverse drains and about 1,000 running feet of longitudinal drain had been completed, but that the 2,000 running feet of dry stone wall allowed for in the original estimate had not been found necessary, the longitudinal drain being found on examination of the interior of the bund to fulfil the required purpose. The cost of the works was therefore reduced to ₹9,800.*

* Proceedings, Madras Government, No. 498 I. of August 6th, 1881.

The parapet wall, the raising of which had been recommended as stated in paragraph 11, had been completed at a cost of ₹2,284. The Chief Engineer for Irrigation, who inspected the tank in November 1881, remarked that "the transverse drains which have been inserted in the bank have acted well, but until the water has risen to somewhat above F. T. L., their sufficiency must not be taken for granted." The weir crest was then only at 43·31 or 3 feet below F. T. L., being so maintained as a measure of precaution pending the completion of the surplus sluices. Provision for this has been included in the revised estimate for the project printed in Proceedings, Madras Government, No. 849 I. of December 9th, 1881.

16. The dangers to which the Red Hills tank has been exposed, and the difficulties that have been experienced in meeting them, as summarised above, afford a very valuable precedent to Engineers engaged on similar works, and it may be well to point out briefly the causes of the difficulties that have arisen and the precautions that should have been originally taken.† Unfortunately the mistakes of the past are hardly capable of being entirely remedied in the present. The slips that have occurred at several points were undoubtedly due to water getting into the bank, whether at points above ground surface or through sub-soil leakage has not been very clearly ascertained, but probably both. The origin of the leakage is to be found in the omission to provide—(1) an adequate puddle wall in the first instance, (2) for the freedom from soakage of the base of the rear slope, while (3) the widening of the bank was made on both sides instead of only on the tank side, and (4) the puddle wall was placed in rear of the revetment and its backing, but was carried down only into the foreshore of the old bank instead of below original ground level; its thickness and height were likewise inadequate. Seeing that much of the old bank was founded on porous laterite, it is probable that no puddle wall placed as above mentioned would have been fully effective, for water would have been liable to pass through the sub-soil and to come to the ground surface under the bank. The proper arrangements would therefore have been—

† Inspection Notes of the Chief Engineer for Irrigation, dated 30th September 1878.

(1) To have aligned the enlarged bank, so that all, or nearly all the necessary widening should have been on the tank side of the old bank.

(2) To have placed the puddle wall on about the centre line of the new bank with its foundations 4 or 5 feet as a minimum below original ground level.

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(3) To have constructed a longitudinal drain at ground level immediately in rear of the puddle wall, with cross drains at intervals, to carry leakage away to the rear of the bank. These precautions, if carried out at the time, would not have added much to the cost, and so arranged, the bank would have been perfectly stable.

(2) *Cholavaram Tank.*

17. The circumstances as regards the Cholavaram tank have been very similar to those of the Red Hills, though in a minor degree. The bank of the Cholavaram tank slipped badly for a length of 80 feet and to a less extent for a length of 112 feet more near the south end, commencing at a point about 900 feet north of the head sluice to the delivery channel, after the heavy rains of October 1870.

No water was found in the bank, and it was therefore considered* probable that the slip was not due to any percolation of tank water, but to the rain having found its way down the cracks to the lower part of the new bank, which in settling might have been pushed outwards by the rear slope of the old bank. The remedies consisted in—

* Proceedings, Madras Government, No. 2774 of 18th November 1870.

(1) Making transverse cuts 3 feet wide down to 3 feet below the level of the water in the rear of the bank, and filling these in with large lumps of laterite;

(2) Cutting a longitudinal trench from end to end of the slip in rear of the bund, also to a depth of 3 feet below the water level, and in this building a dry stone wall 6 feet high, with width of base 6 feet, and of top 3 feet, the batter being towards the rear of the bank. The face of this wall at the original ground level was on a line with the toe of the rear slope of the bank where undisturbed. The soil below this wall was well-consolidated, that over the transverse cuts being also carefully filled in, so as to give additional support to the wall.

(3) The earth of the slip was consolidated by means of rammers, and stepped so as to give a firm base for the new earth required to bring the bank to section.

(4) The bank was raised to the height at which it stood before the slip occurred, the new† earthwork being removed from the back to the front of the old bank, and the rear slope brought to section. The cost of these repairs, charged as new work, was Rs. 30,675.

† Paragraph 5 of Major Scott's Memorandum in Proceedings, Madras Government, No. 1926, of 1st August 1873.

These precautions proved successful, and during the monsoon of 1871 no further signs of failure were apparent.

18. But during the rains of 1872, when, as stated in paragraph 3, the Red Hills bank slipped, the Cholavarram bank also slipped at a point a short distance to the north of the slip of 1870. The portion then repaired continued to stand well, and the new slip was considered‡ to be due to the nature of the soil, a light-coloured clay of the regur class, of which the new bank was composed at that point. The portion that had slipped was cleared away, and new soil was in process of being added when the continuation of the slip was announced,§ and a full report on the preventive measures to be adopted was called for. Slight slips occurred at the same spot in 1873, but these were not of much importance and were considered‖ to be due rather to the evaporation of the water used in re-making the bank than to leakage through the bank. It was eventually decided¶ to reform that portion of the bank which had slipped by advancing it 33 feet in the same way as had been done by Major Scott for the first slip of 1870. The estimate for this re-formation amounted to Rs. 30,675** and was sanctioned in Proceedings, Madras Government, No. 271 of 4th February 1874.

‡ Proceedings, Madras Government, No. 1926 of 1st August 1873.

§ Proceedings, Madras Government, No. 3014 of 18th December 1872.

‖ Proceedings, Madras Government, No. 1045 of 23rd April 1874.

¶ Proceedings, Madras Government, No. 2876 of 27th November 1873.

** Actual cost Rs. 29,832.

19. The Cholavaramt Tank bank stood very well during the heavy rains and flood of October 1874, only a small general settlement occurring†† where the bank had been turned over, and as it has given no further cause for anxiety since that date it may now be considered as stable. When inspected by the Chief Engineer for Irrigation in November 1881, although reported as "by no means in good order," this referred solely to the general condition of the bank, which ordinary repairs would suffice to put right, and not in any way to the sinking of, or leakage through, the bank, both of which have now quite ceased.

†† Proceedings, Madras Government, No. 2011 of 15th July 1875.

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CHAPTER IV.

The Town Supply of Madras.

The town supply and the principal phases of the history of the project are naturally so intimately connected, that a good deal concerning the former has inevitably been stated in Chapter II. The circumstances with regard to it may now be amplified and completed so far as the records of the Irrigation Office render possible, but it must be premised that as the Public Works Department has nothing to do with the supply when once it has left the Red Hills tank, the account must necessarily be confined to statements of the volumes supplied, the price paid, and so on, and cannot go into the details of distribution.

2. In Mr. Fraser's original scheme, 40 million cubic yards* constituted the Municipal share of the assumed total additional supply of 100 million cubic yards.† The population of Madras was then supposed to be 470,000,‡ and assuming it to be half-a-million, and allowing 20 gallons a day per head, which he stated to be a very liberal allowance, Mr. Fraser found that the required supply was 585,686,295 cubic feet. The difference was to make up for waste, loss by evaporation, special cases of consumption, &c.

* 1,080 million cubic feet.

† 2,700 million cubic feet.

‡ Paragraph 10 of report, but see paragraph 10 of Chapter II, and Note.

3. In preparing its distribution scheme, however, the Municipality preferred to adopt the principle of distribution by gravitation in order to escape the expenditure entailed by the use of steam-power in raising the water and delivering it under artificial pressure. This advantage was necessarily gained by a sacrifice of quantity, the water having, in consequence, to be drawn off from the Red Hills Reservoir at a level 6 feet above that originally contemplated. The supply available was thereby reduced to 864 million cubic feet, and the question of Municipal supply was also affected in another way. There is no doubt that it was not contemplated originally to make any charge for the water supplied, and it was not till the raising of the level§ of delivery of the water, and the consequent loss of 418½ million cubic feet of storage, that the question of payment for water actually delivered arose. This change in level reduced the estimated returns from irrigation under the works to ₹53,000, and it was considered that they could not be deemed remunerative unless 7 per cent., or ₹56,000, was realised on the then estimated expenditure of 8 lakhs. There was thus a deficit of ₹3,000, and it was proposed that this should be met by charging the Municipality the same price, as that estimated to be yielded by irrigation, or at the rate of ₹7 per 189,000 cubic feet, or 7,000 cubic yards, which was the volume said to be required for the irrigation of one acre. The Government in affirming the proposed charge said that it recognised a prior claim on behalf of the Municipality to 864 million cubic feet per annum.‖ The charge to be made was finally confirmed in G. O. No. 2327 of 17th July 1869, on letter from the Government of India, No. 126-A.I. of 25th June 1869, in which it was said that the price would be at the rate of Re. 1 per 1,000 cubic yards or 27,000 cubic feet. No doubt a great mistake was made,¶ from a Public Works point of view, in the wording of G. O. No. 3409 of 30th October 1868, for it would only have been equitable that the Municipality should have paid for the whole of the 864 million cubic feet (32 million cubic yards) which were reserved for it. But there is also no doubt it was then supposed that the whole volume would be utilised every year, for in all the many calculations of profit that were made at and after this time, Rs. 32,000 were invariably entered among the probable receipts. The population to be supplied had been shown by the Census returns of 1871 as not likely to exceed 312,000,** the higher number that had been assumed by Mr. Fraser being attributable to the erroneous ideas held as to the number of inhabitants of Madras in 1866.†† The 864 million cubic feet were held to be quite sufficient for the wants of 312,000 people, though why that exact volume was fixed upon is not very clear. It appears to have been purely arbitrary, and the reduced supply required might more properly have been assumed at 675 million cubic feet or 25 million‡‡ cubic yards, which would have allowed an ample margin even for the development of Mr. Clarke's Drainage Scheme, which was prepared in 1875, but which has not yet been, nor is at present likely to be carried out, owing to the inability of the Municipality to provide the necessary funds. Under these circumstances even the reserve of 675 million cubic feet was clearly excessive. In the letter of the President of the Municipality, No. 271 G. of July 21st, 1875, printed in Proceedings,

§ Paragraph 2 of G. O. No. 2981 of 21st October 1875.

‖ Proceedings, Madras Government, No. 4309 of 30th October 1868.

¶ Proceedings, Madras Government, No. 1287 of 5th May 1875.

** *Vide, inter alia,* Proceedings, Madras Government, No. 1287 of 5th May 1875.

†† Proceedings, Madras Government, No. 2981 of 21st October 1875.

‡‡ Proceedings, Madras Government, No. 2981 of 21st October 1875.

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Madras Government, No. 2981 of October 21st, 1875, it is stated that the Commissioners hope by the extension of pipe-laying to reach ultimately a consumption of 20 gallons per head per day for a population of 312,000, or a total of364·5 million cubic feet per annum; but, it is. added, they neither desire nor expect to exceed that consumption to any considerable extent. In the same letter it is stated that the actual consumption was then 9 gallons per head per day for 280,000 consumers. In the report of the President, printed in Proceedings, Madras Government, No. 620 of April 4th, 1876, the consumption is said to amount to 920,376 cubic feet (34,088 cubic yards) per diem, equivalent to 20 gallons per head for a population of 280,000 or 12½ million cubic yards per annum. The reason for this sudden increase in consumption is not stated, and there is probably some discrepancy in one of the returns; but at the present time it may be said that the actual consumption is not likely to exceed 12 million* cubic yards annually, and by G. O. No. 598-A.I. of October 10th, 1879, it was settled that no more water than at present would need to be reserved for municipal use.

* Paragraph 2 of G. O. No. 4921 of 5th August 1881.

4. The following table shows the consumption year by year up to end of 1881. Water was first supplied to the Municipality from the reservoir during May to September 1872, but no record of the volume used is extant:—†

† Proceedings, Madras Government, No. 1287 of 5th May 1875.

Periods.	Quantity in Million Cubic Yards.	Quantity in Million Cubic feet.
From January 1873 to December 1873	5·25	141·75
From „ 1874 to „ 1874	5·36	144·72
From „ 1875 to March 1875	1·36	36·72
From April 1875 to „ 1876	11·986	323·622
From „ 1876 to „ 1877	5·698	153·846
From „ 1877 to „ 1878	3·428	92·556
From „ 1878 to „ 1879	5·693	153·711
From „ 1879 to „ 1880	5·07	136·89
From „ 1880 to „ 1881	6·006	162·162
From „ 1881 to December 1881	3·835	103·545

5. It was stated in the last paragraph of Chapter II that the total cost of the project has been divided in certain proportions between Imperial and Provincial Funds, and the reason that led to this division, the proportions adopted, and how they were obtained may now be explained. A brief recapitulation of paragraphs 12 and 13 of Chapter II is necessary as a preliminary. When, in 1873, it was found that the actual expenditure amounted to ₹12,25,558, ₹10,17,748 of which had been met from Loan Funds, it was proposed by the Government of India in a despatch to the Secretary of State, No. 27 of February 21st, 1873, to charge only 8 lakhs, the amount of the original estimate, finally against Loan Funds, and to recover the balance from the Ordinary Agricultural and Provincial assignments. This proposal, however, did not meet with the approval of the Secretary of State, who directed in his despatch No. 59 of July 10th, 1873, that no part of either principal or interest of the money laid out on the scheme should be eventually debited to Extraordinary Funds. The Government of India in giving effect to these instructions informed the Government of Madras in letter No. 854 I. of December 9th, 1873, that it was considered that 2 lakhs of the outlay from Loan Funds should be made good from Provincial Funds, leaving the balance, which then amounted to Rs. 8,17,748, to be met from the Ordinary Imperial grant. The theory that Provincial Funds should bear the share of the total cost represented by the proportion of the volume reserved for the use of the Municipality to the total volume stored appears to have been first stated in paragraph 17 of the Note of the Chief Engineer for Irrigation, printed in Proceedings, Madras Government, No. 1548 of June 2nd, 1875. It is there said: "with the town supply Agricultural Funds have properly nothing to do, and Provincial Funds appear to be the only other source from which this share of the cost can be defrayed." The principle being admitted, it only remained to determine the volume of water that had to be reserved for the Municipality.

The necessary calculation was made in 1876. The total capacity of the two tanks was stated‡ to be as follows:—

‡ Proceedings, Madras Government, No. 21 of 5th January 1876.

	Millions of Cubic yards.	Millions of Cubic feet.
Cholavaram Tank	28·47	768·69
Red Hills do.	101·98	2,753·46
TOTAL	130·45	3,522·15

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and the capacity of the tanks before the commencement of the project having been*—

* Proceedings, Madras Government, No. 21 of 5th January 1876.

	Millions of Cubic yards.	Millions of Cubic feet.
Cholavaram	3·36	90·72
Red Hills	20·48	552·96
TOTAL	23·84	643·68

The additional storage provided amounted to 106·61 million cubic yards or 2,878·47 million cubic feet. One-fifth of the total capacity was assumed as the extra supply during the year, making the total amount stored 156·54 million cubic yards or 4,226·58 million cubic feet, and the additional amount stored 132·7 million cubic yards, or 3,582·9 million cubic feet. The sill of the lowest municipal pipe being at 31·31, or 15 feet below F.T.L., there remained 20·48 million cubic yards, or 552·96† million cubic feet, below this, which in any case would have to be reserved to keep up the town supply. Further, it was found that a head of not less than 3 feet‡ above this sill was required to ensure a proper flow down the municipal channel, rendering a further reserve of 11·06 million cubic yards, or 298·62 million cubic feet, necessary. Finally, from certain calculations that had been made of the issues and receipts of water, combined with the contents of the tanks at different dates, it appeared that the proportion of issues to consumption averaged 1 to 2½, § so that 12 million cubic yards, or 324 million cubic feet, being the estimated yearly supply required by the Municipality, $12 \times 2\frac{1}{2} = 30$ million cubic yards, or 810 million cubic feet, would have to be reserved for it. Thus altogether 20·48 + 11·06 + 30 = 61·54 million cubic yards, or 1,661·58 million cubic feet of the additional storage was the total estimated amount required to be reserved for the town, leaving 71·2 million cubic yards, or 1,922·4 million cubic feet, as the average annual amount available for irrigation.‖

† 547·917 million cubic feet, according to Colonel O'Connell's table given in Appendix A.

‡ A head of 6 feet had been decided on as necessary in G.O. No. 2981 of 21st October 1875, and no authority is quoted for the reduction.

§ The necessity for allowing for evaporation had been strangely lost sight of in all previous calculations. The proportion assumed is very nearly correct—*vide* paragraph 4 of Chapter VI.

‖ Proceedings, Madras Government, No. 1090 of 1st May 1876.

7. The total additional supply provided by the works being, as above stated, estimated at 132·7 million cubic yards, the portions reserved for the purposes of Municipal supply and irrigation were respectively $\frac{61·5}{132·7}$ and $\frac{71·2}{132·7}$, or in round numbers 46 and 54 per cent. This therefore became the proportion in which the shares of Capital and Revenue expenditure had to be divided.¶

¶ It will be shown in Chapter VI, paragraph 6, that the asumption that one-fifth more than the full capacity is received annually is incorrect, and that the additional amount stored is therefore less than 132·7 million cubic yards. The Municipal share of the expenditure should properly, therefore, be higher than 46 per cent.

Of the total of the revised estimate, printed in Proceedings, Madras Government, No. 849 I. of December 9th, 1881, amounting to ₹18,54,463, the Provincial share is thus ₹8,72,358, divided into—

	₹
Direct charges	7,36,295
Indirect do.	1,36,063

The share of the annual maintenance charges debitable to Provincial is ₹3,342,** so that the charges against Revenue amount to—

** Proceedings, Madras Government, No. 849 I. of 9th December 1881.

	₹
Interest on ₹7,36,295 at 4½ (¹) per cent.	33,133
Maintenance charges	3,342
TOTAL	36,475

Against this receipts from the Municipality are not likely to exceed ultimately ₹12,000, so that the Government contribution to the water-supply of Madras will be but little under ₹24,500 a year, and at the present time it is considerably more.

8. The following is a brief description of the arrangements for the conveyance of the town supply from the Red Hills Reservoir to within Municipal limits. Mr. Fraser's original proposal was to take the municipal supply channel from the reservoir to the Spur Tank in Madras, and thence through properly prepared filter beds into a covered-in water basin. From this basin, which was to have held three or four days' supply, the water was to pass to the pump well, placed at some central point, whence it might have been raised into an elevated cistern, and so

(¹) Under recent orders the charge for interest will be reduced to 4 per cent.

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distributed to various parts of the city.* The area of land to be taken up by the supply channel of this design was 56·2 acres.

But this arrangement did not suit the Municipality, which wished to have the water delivered at a higher level, so as to be able to distribute it by gravitation throughout the town, and thus avoid all the expense of pumping. A new line was therefore chosen, which however took up an area of 160·28† acres, and increased the land compensation from ₹15,887 ‡ to ₹42,270.§

* Proceedings, Madras Government, No. 1102 of 11th April 1866.

† 156·98 acres actually taken (Proceedings, Madras Government, No. 849 I. of 9th December 1881).

‡ Proceedings, Madras Government, No. 492 I. of 5th August 1881.

§ Proceedings, Madras Government, No. 849 I. of 9th December 1881.

9. The water on issuing from the Municipal sluice in the Red Hills Tank is discharged into a basin 80 feet in diameter, which is divided by two parallel walls 6 feet apart. The space between was intended to be filled with charcoal, and thus act as a filter, but as this horizontal filtration proved to have no effect whatever on the water, the filtering medium was removed. The water in this basin is usually at a depth of 2½ feet. From the basin the water falls over an ordinary shutter weir into the Municipal supply channel. In section, this channel, which is not however very regular, is 6 feet broad at bottom, with side slopes of 2 to 1. The depth from the level of the top of the banks is 7½ feet, so that the extreme breadth between the banks is 36 feet. The depth of flow is 3½ feet. The outside slopes of the retaining banks are 1½ to 1, whether in cutting or embankment. The length of the channel is 6 miles 33½ chains, and the fall being at the rate of 3 inches per mile, ‖ the level of the bed of the channel where it ends is 29·61.¶

‖ The observed velocity is 58 feet per minute.

¶ The level of the sill of the Municipal sluice is 31·31.

The water from the channel is delivered into a circular well 22 feet in diameter, called the masonry shaft. From this well, which is within Municipal limits, the distribution takes place. The head available is 29·61 feet, the level of the bed of the channel, *plus* 3½ feet, the depth of water in it, or a total of 33·11 feet above mean sea level. The main pipe from the masonry shaft is 42 inches in diameter and 1,485 yards in length. It there divides into two pipes of 36 and 30 inches diameter, respectively, from which minor off-takes proceed.

10. Large numbers of the inhabitants whose houses are situated in the vicinity of mains have the water brought into their houses. These house services, which are paid for by the house-owners, cost from ₹50 to ₹200 each, and in some cases as much as ₹700. Their adoption is developing, the figures being—

	No.
Up to April 1878	240
To end of April 1878	292
„ of „ 1879	428
„ of September 1880	574

In some cases people have joined together and paid the total cost of the main in their street as well as for the separate house services. The amounts so paid have been as high as ₹4,000. The water-tax is at the rate of 4 per cent. on the rental, and the amount allowed is 1,000 gallons for each 4 annas paid, but there is practically no measurement. For public use, cisterns, wall taps, and pillar fountains are employed, the numbers of each being 42, 84, and 113. The cisterns do not answer.

Water for non-domestic purposes is charged 2 annas per 1,000 gallons, and from ₹ 1,205 to ₹ 1,500 yearly is collected from this source.

11. The actual cost of the Municipal distribution works has been ₹14,30,000 against the original estimate of ₹12,80,000—*vide* paragraph 14 of Chapter II. It is universally admitted, however, that the works need to be improved. An off-take from the Red Hills Reservoir at a lower level, a closed pipe to Madras, and pumping and filtering works, would seem to be what are most required, but the Municipality is scarcely in a position to devote the necessary funds to these objects. A scheme for the improvement of the works was prepared by the Municipal Engineer in 1877, at an estimated cost of ₹ 13,66,334, but no action regarding it has yet been taken.

This account of the Municipal works is from the Municipal Engineer's (J. A. Jones, Esq.) report, printed in Proceedings, Madras Government, No. 1038 W. of 22nd April 1881.

CHAPTER V.

The Irrigation under the Works.

The only point that need be noticed with regard to the irrigation under the project is the various estimates that have been formed from time to time of the area that might be irrigated. The point is one that has always been of the highest importance in connection with the works, for on account of the small demand for water made by the Municipality, and the

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extremely low price at which the supply has been given, the project has always virtually depended on the returns from irrigation to cover the charges for maintenance. Nevertheless, as the project was primarily undertaken for the supply of water to the city of Madras, the volume available for irrigation has of necessity been directly dependent on that which has had to be reserved for Municipal consumption.

2. In Mr. Fraser's original estimate, 60 million cubic yards* were said to be available for irrigation. This at 7,000† cubic yards per acre, which was Sir Arthur Cotton's allowance, would suffice for 8,571 acres, on which the increased assessment, assumed at ₹7 per acre, would amount to nearly ₹60,000 a year. The raising of the sill of the Municipal sluice in the Red Hills tank 6 feet (from 25·31 to 31·31), noticed in the last chapter, involved, however, the sacrifice of 150 million cubic yards‡ available for irrigation. On the assumptions that about 53§ million cubic yards would thus be left for use, and that the irrigating duty and water-rate remained as above stated, the probable return was thus reduced to ₹53,000.‖

* 1,620 million cubic feet.
† 189,000 cubic feet.
‡ 418½ million cubic feet.
§ 1,431 million cubic feet.
‖ Minute by His Excellency the President in Council (Lord Napier), dated October 1868.

3. The Committee appointed in 1871 (G.O. No. 1518 of June 5th) to report on the estimates for and the probable return from the works, arrived at a very different calculation of profit. Major Ryves, then Acting Chief Engineer for Irrigation, took¶ 160 million cubic yards as the average quantity of water stored by the tanks in one year, from which he deducted 45 million cubic yards for loss by evaporation and 32 million cubic yards as the reserve for the town supply, leaving 83 million cubic yards available for irrigation, or enough for about 11,000 acres. The then estimated average area of old wet cultivation was 4,980 acres, so that about 6,000 acres of additional area were expected to be cultivated. The average increased assessment was now however reduced to ₹3¼, so that the net profit became only ₹18,000, thus:—

¶ Proceedings, Madras Government, No. 2171 of 23rd August 1871.

	₹
6,000 acres at ₹3¼	22,000
Add average remission saved on old wet	7,500
	29,500
Deduct for maintenance	11,500
NET PROFIT	18,000

4. In 1876 more reliable calculations as regards the amount of water available for irrigation were made, as was stated in the last chapter. The volume that could be depended upon amounted, it appeared, to 71·2 million cubic yards, or 1,922·4 million cubic feet. The former average area of irrigation was now assumed as 3,284 acres, though it is not very clear whence these figures were derived, and on the assumption that the increased water-supply available for irrigation would suffice for an area proportionate to that irrigated by the volume contained by the tanks when unimproved, the total area of irrigation was taken at 9,852 acres, giving an increased area of 6,568 acres, which would yield a gross revenue of ₹26,272

The net return thus became—

	₹
Irrigation revenue	26,272
Add average remission	7,500
	33,772
Deduct for maintenance	11,500
TOTAL	22,272

5. It was not, however, till the revised estimates were submitted in 1881** that the correct return was calculated. The irrigable area is therein taken at 9,852 acres, as above, but the average old cultivation is increased to 3,829 acres, leaving 6,023 as the ultimate increased irrigated area. Of this it is estimated that 4,926 acres will be double cropped, and the ultimate gross receipts are taken at ₹24,741. From this maintenance and collection charges have to be deducted. The average maintenance charges from 1870-71 to 1879-80 have been ₹8,969, excluding 1871-72 and 1873-74, in which years the outlay was abnormal. From this amount the assumed cost of maintenance of the old tanks, ₹1,704,†† has to be deducted, leaving ₹7,265. This again has to be divided into the proportions of 54 per cent. chargeable to Irrigation or Imperial, and 46 per cent. chargeable to Provincial, for reasons that were explained in the last chapter. The irriga-

** Proceedings, Madras Government, No. 849 I., of December 9th, 1881.

†† Works, at 10 per cent. on average old revenue . . 1,311
Establishment, &c., at 30 per cent. on works . . 393
TOTAL . 1,704

Proceedings, Madras Government, No. 2650, of October 2nd, 1876.

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tion share is thus ₹3,923. To this has to be added the charge for collection at 7·2 per cent. on revenue, or ₹1,781, making the total ultimate charge against revenue account ₹5,704, and the net ultimate earnings due to irrigation ₹19,037. The revised estimate amounts to ₹18,54,463, and the Imperial share of this in the above-mentioned proportion of 54 per cent. is ₹9,82,105, divided into—

	₹
Direct charges	8,32,944
Indirect charges	1,49,161

The estimated return from irrigation therefore amounts to 2·28 per cent. on Direct charges, and to 10 19· per cent. on Direct and Indirect charges.

6. The last year for which actual figures are available is 1879-80, and then the irrigated area under first crop was 2,618 acres, and under second crop was 2,769 acres. The gross receipts were ₹12,149, the maintenance charges were ₹3,441, and the collection charges ₹875, total ₹4,316, leaving ₹7,833 as the net receipts.

7. A description of the irrigation sluices has been given in Chapter I. The following is the description and cost of the conservancy establishment maintained for the works:—

		₹
1	Superintendent	25
1	Do.	15
4	Lascars at 7 rupees	28
2	Do. at 6 „	12
4	Do. at 5 „	20
	TOTAL PER MONTH	100
	TOTAL PER YEAR	1,200

NOTE.—The figures in this chapter, so far as regards acreage and revenue, refer to the project as a whole.

CHAPTER VI.

HYDRAULIC DETAILS.

It will be sufficient to confine the hydraulic information to be given in this chapter to that which concerns the Red Hills tank, which is by far the largest and most important of the two reservoirs. Colonel O'Connell's tables of area and contents at ½ foot intervals for the Cholavaram tank are however given in Appendix C, as well as the corresponding information for the Red Hills tank in Appendix B.

In addition to these tables the Monthly Statements of Receipts and Issues have been abstracted for the last five years in Appendix A, and after having first briefly explained how the abstract has been prepared, the conclusions to be drawn from it will then be summarised.

2. Colonel O'Connell's tables for the Red Hills (Appendix B) only show the difference of area and contents as each half-foot; but for the purposes of Appendix A, it has been assumed that for each half-foot the differences between each 0·1 of a foot proceed in arithmetical progression. On this basis the contents at the levels shown in column 2 for the beginning of each month and in column 8 for the end of each month have been calculated and are therefore approximately correct to 0·05 of a foot. The method adopted does not give absolutely correct results, but is accurate enough for all practical purposes.

Similarly, columns 16 and 17 show the areas corresponding to the contents in columns 3 and 9. Columns 4 and 5 show respectively the receipts through the supply channel and by means of rainfall. The former are obtained by direct measurement of the depth of water passing over the sill of the head sluice in Cholavaram tank; the latter by deducting these from the total receipts as calculated by the differences of water level. Column 6 shows the total receipts, and column 7 the sum of these receipts and of the volume in the tank at the beginning of the month.

Column 10 shows the loss during the month, *i.e.*, the difference between the above sum and the volume in the tank at the end of the month.

Columns 11 and 12 show the issues during each month to Irrigation and to the Municipality respectively by direct measurement.

Column 13 shows the total of these, and

Column 14 the difference between this and the total loss, which is therefore the loss due to evaporation and overflow.

Column 15 gives the proportion that the total volume lost bears to the total volume issued.

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Column 18 gives the *mean* area of the tank during the month.

Column 19 shows the total depth over the mean area lost by evaporation during the month, and lastly

Column 20 shows the average depth evaporated daily.

3. The figures entered as above stated show discrepancies here and there; as, for instance in June 1877, when the total at the end of the month is more than the sum of the receipts and of the volume in the reservoir at the beginning of the month; or as in December 1879, when the difference between the beginning and the end of the month is less than the consumption. But in a long series of somewhat elaborate measurements which cannot be constantly checked by a responsible officer, it is inevitable that some such discrepancies should occur, and they are not numerous enough to prejudice the general accuracy of the results.

Again, as the discharge over the weir and through the weir vents has not been gauged, no calculation has been made as regards the amount of evaporation for those months in which surplus is discharged. This removes to a certain extent the monsoon months—October, November, and December—from the calculations, to which may be added September, when heavy rain often falls.

The general result obtained is however as follows—

That in the five years the average daily evaporation is 0·28 of an inch, and as the average mean area is 149·5026 million square feet, it would result that the average daily loss by evaporation is 3·4884 million cubic feet.*

* But see next paragraph.

The average result month by month is as follows :—

How obtained.	Average daily evaporation. Inches.
From four Januarys	0·24
„ two Februarys	0·24
„ five Marchs	0·26
„ five Aprils	0·3
„ five Mays	0·37
„ four Junes	0·3
„ four Julys	0·33
„ five Augusts	0·32
„ one September	0·38
„ two Octobers	0·27
„ one November	0·27
„ two Decembers	0·13

Taken as a whole, these results accord very fairly with what might be expected, the evaporation increasing gradually up to the hot months and then gradually subsiding. The figures for September, for which it has been possible to make only one calculation, are undoubtedly too high.

4. The statement further shows that the proportion the average volume lost bears to the average volume used is as high as 5·8 to 1, but this includes 1877, when the issues to irrigation were stopped for some months, and those to the Municipality were very limited, owing to the low level of water in the reservoir, and when therefore the issues in each case were very much below the average (see below). Excluding 1877 this proportion that the volume lost bears to the volume used is 2·888 to 1.

The average receipts during the five years were :—

	Million Cubic Feet.
From Supply Channel	889·2994
Rainfall	627·7973
TOTAL	1,517·0967

The average issues were—

	Million Cubic Feet.
To Irrigation	405·591
„ Municipality	131·8222
TOTAL	537·4132

The proportion of average issues to average receipts is thus 1 to 2·82, which shows a very close agreement with what is practically the same proportion last given. The proportion issued to the Municipality to that used for Irrigation is as 1 to 3·07.

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The difference between the receipts and issues *should* represent the loss by evaporation *plus* the discharge over the weir. This difference is on the average 979·6835 million cubic feet a year, while the average evaporation obtained from column 14 of Appendix A is 913·4078 million cubic feet. This leaves 66·2757 million cubic feet as the average yearly surplus discharge. The average yearly evaporation as last given represents a daily evaporation of 0·208 of an inch as against 0·28 of an inch, as given previously. From this the general conclusion may be derived that the daily loss of depth due to evaporation is over 0·2 of an inch and under 0·3. Probably one-quarter of an inch might be assumed with fair accuracy.

5. The following figures show the quantity of water draining into the tank after a heavy fall of rain. They are obtained from Colonel O'Connell's report on the cyclone of May 1877, printed in Proceedings, Madras Government, No. 38 I. of January 14th, 1878. This is the only occasion on which observations have been made on this interesting point; and though results of a like nature might be deduced from the figures given in Appendix A, it is not considered that the conclusions so derived would be sufficiently reliable to be of value. In calculations of this sort, a somewhat near approach to accuracy is essential, and this can scarcely be considered as attained, unless observations have been specially taken with reference to the object in view.

The rainfall at the Red Hills tank during the cyclone of May 1877 was :—

	Inches.
On May 17th	1·00
Do. 18th	12·03
Do. 19th	4·88
TOTAL .	17·91

The rise in the surface of the water during this cyclone was entirely due to the drainage from the catchment basin of 23 square miles, which includes the area of the reservoir itself.

The rise and the corresponding drainage are shown in the following table :—

Date.	Level of water surface at 6 A.M.	Corresponding volume in million cubic feet.	Daily difference of level of water surface in feet.	Additional volume entering reservoir.		Drainage in inches over catchment of 23 square miles, which includes reservoir, represented by column 5.
				Per day in million cubic feet.	Cubic feet per second.	
1	2	3	4	5	6	7
May 17th	27·30	253·6886	...	...	...	...
Do. 18th	30·95	517 0018	3·65	263·3132	3,047	4·92
Do. 19th	34·25	838·0862	3·30	321·0844	3,766	6·009
Do. 20th	34·79	921·3674	0·74	83·2812	964	1·56

The quantity draining off in the three days amounts to a total of 12·489 inches. Water continued to run slowly off the catchment basin for nearly a week after the rain had ceased to fall, but the total quantity thus run off did not exceed one-third of an inch, so that the total quantity run off fell short of 13 inches. Taking each day separately the figures in column 7 for the 18th and 19th of May give coefficients of discharge of 377 and 466 respectively for Ryve's formula

$$D = CM^{\frac{2}{3}}$$

and co-efficients of 290 and 359 respectively for Dickens' formula

$$D = CM^{\frac{3}{4}}$$

It is more than probable, however, that these co-efficients are too small to represent the maximum discharge, which, especially in the case of cyclonic rain, would doubtless considerably exceed the average discharge from which they are obtained.

The table shows that the average rate at which the rain was discharged from the drainage basin between the 18th and 19th of May was 6·009 inches per diem.

The figures given above furnish the nearest reply possible to the information asked for in paragraph IV (V) of Circular No. XXX, dated September 24th, 1880, from the Government of India. The percentage which the volume stored bears to the volume falling on the catchment area, excluding that of the reservoir, after certain recorded falls of rain is there referred to. But accurate information on this point is almost impossible to obtain except in the case of a very small catchment. In the case of a large area no reliance could be placed on the results unless the rainfall were registered at several stations. In the instance given it has been supposed that the whole of the rain that fell was stored, but if the registered rainfall at the reservoir of 17·91 inches was taken over the whole catchment, the percentage stored would be 69.

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6. The following figures comparing the average consumption for irrigation and municipal use with the storage reserved will be of interest.

The capacity of the reservoir when full is 2,744·8911 million cubic feet, of which 2191 9311 are increased capacity due to the improvements. This increase divided in the proportions of 54 and 46 as explained in Chapter IV gives 1183·6428 million cubic feet as reserved for irrigation, and 1008·2883 for municipal use. The average annual consumption in each case given in paragraph 4 above is therefore 34·2 per cent. and 13 per cent. of the reserve respectively.

But it is to be observed that the proportions in which the whole volume is divided do not appear to be correct. It was assumed in making the calculation, as explained in paragraph 6, Chapter IV, that $\frac{1}{3}$th more than the whole contents of the reservoirs was annually stored, but from paragraph 4 above, it appears that the average annual volume stored in the Red Hills Reservoir, which may be taken as representative, is only 1,517·0967 million cubic feet, or 69 per cent. of the whole capacity of the reservoir. As, however, the level of the water is never supposed to fall below 34·31, it would be sufficient to assume the full reservoir as the volume annually available, and the average amount actually reserved for municipal use would then be :—

	Million Cubic Feet.
[1] Volume below 34·31 . . . . . =	851·58
[2] 2·888 times average consumption	380·70
TOTAL .	1,232·28

which is rather more than 56 per cent. of the increased capacity. This therefore leaves only 44 per cent. of the storage available for irrigation, and the proportion of volume used to volume reserved becomes 42 per cent. for irrigation and 10·7 per cent. for Municipal use.

7. This Monograph is followed by three Appendices—

APPENDIX A.—Statement of Receipts and Issues of the Red Hills Reservoir from 1877 to 1881.
„ B.—Colonel O'Connell's Tables of Area Contents at Half-foot intervals for Red Hills Reservoir.
„ C.—Colonel O'Connell's Tables of Area Contents at Half-foot intervals for Cholavaram Reservoir.

Also by two plates—

PLATE I.—Catchment Basin of System.
„ II.—Component Works of System.

C. VINCENT,
for *Chief Engineer for Irrigation.*

June 1882.

[1] *Vide* paragraph 6 of Chapter IV. Paragraph 4 above.

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APPENDICES.

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APPEN

Statement of Receipts and Issues of the Red Hills Reservoir, month by month,

N.B.—All volumes are stated
Areas . .
Levels are referred to

Month.	Water Level in Reservoir at beginning of month.	Corresponding Volume.	Receipts during month.			Total Columns 3 and 6.	Water Level in Reservoir at end of month.	Corresponding Volume.	Difference, Columns 7 and 9.
			Supply Channel.	Rainfall.	Total.				
1	2	3	4	5	6	7	8	9	10
									The *plus* figures are excluded from the totals in this column.
1877.									
January	30·65	488·571	...	...	...	488·571	29·83	424·8108	— 63·7602
February . . .	29·81	424·8108	...	...	...	424·8108	29·05	366·1727	— 58·6381
March	29·02	366·1727	...	...	...	366·1727	28·36	318·1683	— 48·0044
April	28·35	318·1683	...	...	...	318·1683	27·52	266·8321	— 51·3362
May	27·49	266·8321	119·583	705·1617	824·7447	1,091·5768	35·16	935·1865	—156·3903
June	36·33	1,083·267	221·1	...	221·1	1,304·367	38·1	1,327·943	+ 23·576
July	38·07	1,327·943	...	...	...	1,327·943	37·07	1,188·8481	—139·0949
August	37·07	1,188·8481	...	...	...	1,188·8481	36·42	1,096·295	— 92·5531
September . . .	36·4	1,096·295	18·1696	...	18·1696	1,114·4646	38·17	1,342 1912	+227·7266
October	38·26	1,342·1912	26·65	...	26·65	1,368·8412	42·6	2,040·3403	+671·4991
November . . .	42·6	2,040·3403	756	54	810·	2,850·3403	42·73	2,057·5175	—792·8228
December . . .	42·84	2,074·6947	...	165·916	165·916	2,240·6107	43·31	2,162·054	— 78·5567
Totals .	416·89	12,018·1342	1,141·5026	925·0777	2,066·5803	14,084·7145	428·25	13,526·3595	1,491·1567
Averages .	34·74	1,001·5111	...	...	...	...	...	...	...
1878.									
January	43·28	2,162·054	...	...	...	2,162·054	42·34	1,988·8088	—173·2452
February . . .	42·31	1,988·8088	9·311	...	9·311	1,998·1198	42·8	2,074·6947	+ 76·5749
March	42·78	2,074·6947	...	...	...	2,074·6947	41·8	1,904·3838	—170·3109
April	41·77	1,904·3838	...	...	...	1,904·3838	40·4	1,675·7727	—228·6111
May	40·36	1,675·7727	...	10·687	10·687	1,686 4597	39·43	1,519·7741	—166·6856
June	39·39	1,519·7741	...	...	...	1,519·7741	37·99	1,313·7947	—205·9794
July	38·08	1,327·943	...	114·036	114·036	1,441·979	37·49	1,243·5927	—198·3863
August	37·46	1,243·5927	...	103·836	103·836	1,347·5287	37·04	1,175 3677	—172·161
September . . .	37·04	1,175·3677	605·197	322·844	928·041	2,103 4087	41·89	1,921·2688	—182·1399
October	41·89	1,921·2688	127·27	161·263	288·533	2,209·8018	42·68	2,057·5175	—152·2843
November . . .	42·66	2,057·5175	208·656	...	208·656	2,266·1735	42·88	2,092·1666	—174·0069
December . . .	42·88	2,092·1666	...	...	...	2,092·1666	42·25	1,971·9238	—120·2428
Totals .	489·9	21,143·3444	950·4340	712·666	1,663·1000	22,806·4444	488·99	20,939·0659	1,944·0434
Averages .	40·82	1,761·9453	...	...	...	...	...	...	...

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DIX A.

during 1877 to 1881 inclusive, showing the volume of water lost by Evaporation.

in Million Cubic Feet.
. . Square Feet.
Mean Sea Level.

Issues during month			Loss by Evaporation, difference between Columns 10 and 13.	Proportion to unity of Volume used (Column 13) to Volume lost (Column 10).	Area of Reservoir at beginning of month.	Area of Reservoir at end of month.	Mean Area.	Evaporation in Inches over Mean Area during Month, Column 14÷ Column 18.	Average Daily Evaporation in Inches.	Remarks.
To Irrigation.	To Municipality.	Total.								
11	12	13	14	15	16	17	18	19	20	21
9·856	3·7887	13·6447	50·1155	4·6729	82·8986	76·888	79·8933	7·52	0·24	The discharge over the weir and through the weir vents not having been gauged, and the weir moreover having been breached in November 1877, the figures for those months in which surplus water was discharged are valueless. The fact of discharge is noticed in each case when recorded.
5·661	3·315	8·996	59·6421	7·6298	76·888	72·1242	74·5061	9·6	0·34	
0·599	3·6229	4·2219	43·7825	11·3703	72·1242	66·246	69·1851	7·59	0·24	
0·355	3·4916	3·8466	47·4896	13·2458	66·246	62·4686	64·3573	8·85	0·29	
0·58	1·7112	2·2912	154·0991	68·2569	62·4686	117·595	90·0818	20·53	0·66	Cyclone . { Rainfall on 17th 1 inch. Rainfall on 18th 12·03 inches. Rainfall on 19th 4·88 inches.
...	9·961	9·961	Discrepancy shown in column 10 not explained.		128·038	142·7882	135·4131	...	...	
...	7·574	7·574	131·5209	18·3648	142·7822	135·2624	139·0223	11·35	0·36	
...	7·3094	7·3094	85·2437	12·6622	135·2624	128·9352	132·0988	7·74	0·25	
...	8·2124	8·2124	See remark for June.		128·9352	143·4996	136·2174	...	...	
14·685	7·5837	22·2687	Do.		143·4996	169·336	156·4178	...	...	
...	7·887	7·887	Discharge over weir.		169·336	172 8472	171·0916	...	...	The west weir was breached.
16·882	6·782	23·664	54·8927	3·3196	173·434	176·394	174·914	3·76	0·12	
48·638	71·2589	119·8969	626·7861	139·6223	...	...	1,423·1486	76·94	2·51	
6·948	5·9382	...	...	17·4528	...	...	118·5957	9·62	0·31	
40·022	9·098	49·12	124·1252	3·5269	176·394	170·5	173·447	8·58	0·27	
39·679	10·292	49·971	Discrepancy in column 10 not explained.		170·5	173·434	171·967	...	...	
66·388	12·172	78·56	91·7509	2·1679	173·434	167·59	170·512	6·45	0·2	
74·733	14·69	89·423	139·1881	2·5565	167·59	159·979	163·784	10·19	0·34	
58·831	14·976	73·807	92·8786	2·2584	159 979	152·2682	156·1236	7·13	0·23	
80·337	14·412	94·749	111·2304	2·1739	152·2682	142·0648	147·1665	9·07	0·3	
39·756	12·871	52·627	145·7593	2·7697	142·7822	138·5048	140·6435	12·43	0·4	
20·016	12·29	32·306	139·855	5·3290	138·5048	134·3496	136·4272	12·30	0·39	
27·18	11·318	38·498	143·6419	4·7309	134·3496	168·172	151·2608	11·38	0·38	
30·863	12·127	42·99	109·2943	3·5423	168·172	172·5472	170·5096	7·69	0·25	
41·056	12·313	53·369	120·6379	3·2604	172·8472	174·026	173·4366	8·34	0·27	
44·879	12·209	57·088	63·1548	2·1062	174·026	169·918	171·972	4·40	0·14	
563·74	148·768	712·508	1,181·5164	34·4221	...	...	1,927·2498	97·96	3·17	
46·9783	12·3973	...	...	3·1293	...	...	160·6041	8·91	0·29	

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Statement of Receipts and Issues of the Red Hills Reservoir, month by month, during

Month.	Water Level in Reservoir at beginning of month.	Corresponding Volume.	Receipts during month.			Total Columns 3 and 6.	Water Level in Reservoir at end of month.	Corresponding Volume.	Difference Columns 7 and 9.
			Supply Channel.	Rainfall.	Total.				
1	2	3	4	5	6	7	8	9	10
1879.									
January	42·22	1,971·9238	..	17·935	17·935	1,999·8588	41·56	1,854·5978	—145·261
February	41·54	1,854·5978	...	...	...	1,854·5978	40·91	1,756·1746	— 98·4032
March	40 89	1,756·1746	219·033	19·57	238·603	1,994·7776	41·4	1,838·0025	—156·7751
April	41·36	1,838·0025	...	...	...	1,838·0025	40·29	1,659·7492	—178·2533
May	40 26	1,659·7492	...	115·923	115·923	1,775·6722	39·98	1,612 5915	—163·0807
June	39·96	1,612·5915	...	...	...	1.612·5915	39·09	1,474·48	—138·1115
July	39·06	1,474·48	...	73 046	73·046	1,547·526	38·52	1,385·7281	—161·7979
August	38·49	1,385·7281	12·15	34·984	47·134	1,432·8621	38·28	1,3 56 5096	— 76·3525
September	38·38	1,371·1188	6·917	...	6·917	1,378·0358	41·69	1,887·7885	+ 509·7527
October	41·66	1,887·7885	...	260	260	2.147·7885	43·4	2,179·9788	+ 52·1903
November	43·45	2,179·9788	...	852·719	852·719	3,032·6978	43·22	2,144·5821	—888·1157
December	43·16	2,144·5821	...	...	...	2,144 5821	43·04	2,109·6384	— 34·9437
Totals	490·43	20,136·7157	238·100	1,374·177	1,612·277	21,748·9927	491·38	21,259·8211	2,041·09466
Averages	40·87	1,678·0596	...	...	...	...	...	...	...
1880.									
January	43·02	2,109·6384	...	27·446	27·446	2,137·0844	42·4	2,005·986	—131·0984
February	42 39	2,005·986	...	...	...	2,005·986	42·07	1,955·0388	— 50 9472
March	42·06	1,955·0388	...	...	...	1,955·0388	41·11	1,788·7909	—166·2479
April	41·08	1,788·7909	...	...	...	1,788·7909	39·65	1,550·4636	—238·3279
May	39·59	1,550·4636	...	...	...	1,550·4636	38	1,313·7947	—236·6689
June	37·93	1,299·5465	...	...	...	1,299·5465	36·06	1,058·1006	—241·4454
July	36·09	1,058·1006	...	...	...	1,058·1006	36·33	1,083·267	+ 25·1664
August	36 89	1,096·295	...	...	...	1,096·295	35·66	996·0587	—100·2363
September	35·65	996·0587	690·62	24·32	714·94	1,710·9987	37·09	1,188·8481	—522 1506
October	37·11	1,188·8481	...	8·3	8·3	1,197·1481	36·93	1,161·8872	— 35·2609
November	36·96	1,161·8872	947·194	54	1,001·194	1,263·0812	44·14	2,307·1827	+144·1015
December	44·24	2,325·6845	144·866	...	144·866	2,470·5505	43·68	2,233 7531	—236·7974
Totals	472·51	18,536·3383	1,782·68	114 066	1,896·746	20,433·0843	473·12	18,643·1714	1,959·1808
Averages	39·37	1,544·6948	...	...	...	...	...	...	...
1881.									
January	43·8	2,251·6779	...	...	...	2,251·6779	43·76	2,233·7531	— 17·9248
February	43·74	2,233·7531	...	...	...	2,233·7531	43·19	2,144·5821	— 89·1710
March	43·17	2,144·5821	...	...	...	2,144·5821	42·21	1,971·9238	—172·6583
April	42·18	1,971·9238	...	...	...	1,971·9238	40·92	1,756 1746	—215·7492
May	40·87	1,756·1746	...	...	...	1,756·1746	39·4	1,519·7741	—236·4005
June	39·34	1,504·4294	...	...	...	1,504·4294	38·22	1,342·1912	—162·2382
July	38·2	1,342·1912	...	...	...	1,342·1912	37·04	1,175 3677	—166·8235
August	37·01	1,175·3677	217·617	...	217·617	1,392·9847	36 48	1,109·3229	—283·6618
September	36·46	1,109·3229	97·2	...	97·2	1,206·5229	37·88	1,299·5465	+ 93 0236
October	37 86	1,299·5465	...	...	...	1,299·5465	36·71	1,135·3788	—164·1677
November	36 67	1,135·3788	18·954	13	31·954	1,167·3328	42 45	2,005 986	+838·6532
December	42·42	2,005·986	...	...	...	2,005·986	42·27	1,988·8088	— 17 1772
Totals	481·72	19,930·3340	333·771	13	346·771	20,277·1050	480·93	19,682·8096	1,525·9722
Averages	40·14	1,660·8611	...	...	...	...	...	...	...

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1877 to 1881 inclusive, showing the volume of water lost by Evaporation—contd.

Issues during month			Loss by Evaporation, difference between Columns 10 and 13.	Proportion to unity of Volume used (Column 13) to Volume lost (Column 10.)	Area of Reservoir at beginning of month.	Area of Reservoir at end of month.	Mean Area.	Evaporation in Inches over Mean Area during Month, Column 14 ÷ Column 18.	Average Daily Evaporation in Inches.	Remarks.
To Irrigation.	To Municipality.	Total.								
11	12	13	14	15	16	17	18	19	20	21
21·686	12 713	34·399	110·862	4·2228	169·918	165·8596	167·8888	7·92	0·25	
37·34	11·038	48·378	50·0252	2·0340	165·8596	162·4188	164·1392	3·65	0·13	
47·777	12·759	60·536	96·2391	2·5897	162·4188	165·2828	163·8508	7·04	0·22	
82·677	11·004	93·681	84·5723	1·9017	165·2828	159·012	162·1474	6·25	0·21	Cyclone; rainfall on 20th 8·75 inches.
52·322	12·228	64·55	98·5307	2 5264	159·012	156·7518	157·8819	7·48	0·24	Cyclone; rainfall on 21st, 0·5 inches.
36·9	11·738	48·638	89·4785	2·8396	156·7518	150·0536	153·4027	6·99	0·23	
46·241	14·507	60·748	101·0499	2·6634	150·0536	145·6694	147·8615	8·2	0·27	
28·437	13·952	42·389	33·9635	1·8019	145·6694	144·217	144·9432	2·81	0·09	
61·871	14·175	76·046	Discrepancy in column 10 not explained.		144·9432	167·0132	155·9782	...	...	
11·055	12·086	23·141	Do.	do.	167·0132	177·5386	172·2759	...	...	Surplus over weir on 31st.
...	9·892	9·892	...	...	177·5386	175·802	176·6703	...	...	Do. almost throughout the month.
30·466	8·687	39·153	Difference (column 10) less than consumption. Discrepancy not explained.		175·802	174·618	175·210	...	...	
456·772	144·779	601·551	664·7162	20·5795	...	...	1,942·2499	50·34	1·64	
41·525	12 065	...	...	2·5724	...	...	161·8542	6·29	0·205	
33·318	9·963	43·281	87·8174	3·0290	174·618	171·0868	172·8524	5·98	0·19	
34·393	7·771	42·163	8·7842	...	171·0868	169·336	170·2114	...	...	Evaporation for this month evidently incorrect, so omitted from averages.
88·43	10·986	94·416	71·8319	1·7608	169·336	163·5624	166·4492	5·11	0·16	
95·162	12·752	107·914	130·4133	2·2084	163·5624	153·7566	158·6595	9·86	0·33	
80·15	15·901	96·051	140·6179	2·4639	153·7566	142·0648	147·9107	11·4	0·36	
74·349	13·777	88·126	153·3199	2·7398	141·3474	126·2744	133·8109	10·74	0·45	
31·932	14·622	46·554	Discrepancy in Column 10 not explained.		126·2744	128·0382	127·1562	...	...	
23·343	16·842	40·185	60·0513	2·4943	128·9352	121·8962	125·4157	5·74	0·18	
15·966	19·459	35·425	486·7256	...	121·8962	135·2624	128·5793	...	...	The loss by evaporation is so high that the figures are evidently wrong, and the averages are therefore not taken.
21·223	23·650	44·873	...	...	135·2624	133·4368	134·3496	...	...	Difference (Column 10) less than consumption. Discrepancy not explained.
...	10·322	10·322	See remark for July.		133·4368	185·606	159·5214	...	...	Surplus over weir on 28th, 29th, and 30th.
5·889	7·698	13·587	...	...	186·1875	180·9724	183·5799	...	...	Surplus over weir on several days.
499·154	163·743	662·897	1,189·5615	14·6962	...	...	1,808·4962	51·83	1·67	
45·378	13·645	...	...	2·4494	...	...	150·708	8·64	0·28	
27·575	8·07	35·645	Difference (Column 10) less than consumption. Discrepancy not explained.		182·117	180·9274	181·5222	...	...	Surplus over weir throughout the month.
20·814	8·114	28·928	...	...	180·9274	175·802	178·3647	...	...	Surplus over weir on several days.
37·795	10·943	48·738	123·9203	3·5426	175·802	169·918	172·860	8·59	0·27	
59·896	12·981	72·877	142·8722	2·9604	169·918	162·4188	166·1684	10·31	0·34	
65·001	16·06	81·061	155·3395	2·9162	162·4188	152·2682	157·3435	11·85	0·38	
70·424	14·499	84·923	77·3152	1·9104	151·524	143·4996	147·5118	6·28	0·21	
49·482	10·156	59·638	107·1855	2·7972	143·4996	134·3496	138·9246	9·25	0·29	
31·547	9·627	41·174	242·4878	6·8893	134·3496	129·8324	132·0910	22·02	0·71	
12·298	8·736	21·034	Discrepancy in Column 10 not explained.		129·8324	141·3474	135·5899	...	..	
48·083	10·796	58·829	105·3387	2·7906	141·3474	131·6268	136·4871	9·26	0·29	
23·906	10·54	24·446	See remark for September.		131·6268	171·0868	151·3568	...	...	
12·881	10·14	23·021	See remark for January		171·0868	170·5	170·7934	...	...	
459·652	130·662	590·314	954·4592	23·8067	...	...	1,869·0134	77·56	2·49	
38·304	10·888	...	...	3·4009	...	...	155·7511	11·08	0·35	

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APPENDIX B.

RED HILLS TANK.

Table showing Water Surface, Areas, and Cubical Contents at half-foot vertical intervals up to crest of New Calingulah.

Height above Mean Sea Level.	Difference of Area for each half-foot.	Area at Level in Column 1.	Difference of Cubical Contents at each half-foot.	Contents at Level in Column 1.
1	2	3	4	5
Feet.	Million Square feet.	Million Square feet.	Million Cubic feet.	Million Cubic feet.
22·31		25·503		25·5015
	3·847		13·6970	
22·81		29·350		39·1985
	4·117		15·6873	
23·31		33·467		54·8858
	4·387		17·8125	
23·81		37·854		72·6983
	4·657		20·0729	
24·31		42·511		92·7712
	4·927		22·4682	
24·81		47·438		115·2394
	5·197		24·9987	
25·31		52·635		140·2381
	2·160		26·8557	
25·81		54·795		167·0938
	2·203		27·9465	
26·31		56·998		195·0403
	2·247		29·0590	
26·81		59·245		224·0993
	2·290		30·1932	
27·31		61·535		254·2925
	2·334		31·3491	
27·81		63·869		285·6416
	2·377		32·5267	
28·31		66·246		318·1683
	3·459		33·7912	
28·81		69·705		351·9595
	3·548		35·5329	
29·31		73·253		387·4924
	3·635		37·3184	
29·81		76·888		424·8108
	3·723		39·1477	
30·31		80·611		463·9585
	3·811		41·0208	
30·81		84·422		504·9793
	3·899		42·9377	
31·31		88·321		547·9170
	3·580		45·0528	
31·81		91·901		592·9698
	3·651		46·7604	
32·31		95·552		639·7302
	3·722		48·5036	
32·81		99·274		688·2338
	3·792		50·2824	
33·31		103·066		738·5162
	3·864		52·0968	
33·81		106·930		790·6130
	3·935		53·9468	
34·31		110·865		844·5598
	4·177		56·4762	
34·81		115·042		901·0360
	4·255		58·5842	
35·31		119·297		959·6202
	4·332		60·7308	
35·81		123·629		1,020·3510
	4·409		62·9160	
36·31		128·038		1,083·2670
	4·486		65·1398	
36·81		132·524		1,148·4068
	4·564		67·4022	
37·31		137·088		1,215·8090
	3·542		69·4592	
37·81		140·630		1,285·2682
	3·587		71·2414	
38·31		144·217		1,356·5096

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Table showing Water Surface, Areas, and Cubical Contents at half-foot vertical intervals up to crest of New Calingulak.—concld.

Height above Mean Sea Level.	Difference of Area for each half-foot.	Area at Level in Column 1.	Difference of Cubical Contents at each half-foot.	Contents at Level in Column 1.
1	2	3	4	5
Feet.	Million Square Feet.	Million Square Feet.	Million Cubic Feet.	Million Cubic Feet.
	3·631		73·0462	
38·81		147·848		1,429·5558
	3·676		74·8736	
39·31		151·524		1,504·4294
	3·721		76·7236	
39·81		155·245		1,581·1530
	3·767		78·5962	
40·31		159·012		1,659·7492
	2·835		80·1173	
40·81		161·847		1,739·8665
	2·859		81·5407	
41·31		164·706		1,821·4072
	2·884		82·9766	
41·81		167·590		1,904·3838
	2·910		84·4250	
42·31		170·500		1,988·8088
	2·934		85·8859	
42·81		173·434		2,074·6947
	2·960		87·3593	
43·31		176·394		2,162·0540
	5·723		89·6239	
43·81		182·117		2,251·6779
	5·815		92·5083	
44·31		187·932		2,344·1862
	5·906		95·4841	
44·81		193·838		2,439·6703
	5·997		98·5513	
45·31		199·835		2,538·2216
	6·088		101·7098	
45·81		205·923		2,639·9314
	6·180		104·9597	
46·31		212·103		2,744·8911

APPENDIX C.

CHOLAVARAM TANK.

Table showing Water Surface, Areas, and Cubical Contents at half-foot vertical intervals up to crest of New Calingulak.

Height above Mean Sea Level.	Difference of Area for each half-foot.	Area at Level in Column 1.	Difference of Cubical Contents at each half-foot.	Contents at Level in Column 1.
1	2	3	4	5
Feet.	Million Square Feet.	Million Square Feet.	Million Cubic Feet.	Million Cubic Feet.
	1·147	17·415		26·123
44·18		18·562	9·000	35·123
	1·183		9·583	
44·68		19·745		44·706
	1·221		10·184	
45·18		20·966		54·890
	1·257		10·803	
45·68		22·223		65·693
	1·293		11·441	
46·18		23·516		77·134
	1·331		12·096	
46·68		24·847		89·230
	1·284		12·743	
47·18		26·131		101·973
	1·317		13·394	

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Table showing Water Surface, Areas, and Cubical Contents at half-foot vertical intervals up to crest of New Calingulah.—concld.

Height above Mean Sea Level.	Difference of Area for each half-foot.	Area at Level in Column 1.	Difference of Cubical Contents at each hal-ffoot.	Contents at Level in Column 1.
1	2	3	4	5
Feet.	Million square feet.	Million square feet.	Million cubic feet.	Million cubic feet.
47·68		27·448		115·367
	1·349		14·060	
48·18		28·797		129·427
	1·382		14·743	
48·68		30·179		144·170
	1·414		15·442	
49·18		31·593		159·612
	1·447		16·157	
49·68		33·040		175·769
	1·241		16·829	
50·18		34·281		192·598
	1·263		17·455	
50·68		35·544		210·053
	1·286		18·092	
51·18		36·830		228·145
	1·309		18·741	
51·68		38·139		246·886
	1·332		19·401	
52·18		39·471		266·287
	1·354		20·073	
52·68		40·825		286·360
	1·194		20·710	
53·18		42·019		307·070
	1·211		21·311	
53·68		43·230		328·381
	1·228		21·920	
54·18		44·458		350·301
	1·245		22·538	
54·68		45·703		372·839
	1·262		23·165	
55·18		46·965		396·005
	1·279		23·800	
55·68		48·244		419·804
	1·532		24·502	
56·18		49·776		444·306
	1·556		25·273	
56·68		51·332		469·579
	1·580		26·058	
57·18		52·912		495·637
	1·604		26·854	
57·68		54·516		522·491
	1·628		27·661	
58·18		56·144		550·152
	1·651		28·481	
58·68		57·795		578·633
	1·520		29·277	
59·18		59·315		607·910
	1·539		30·071	
59·68		60·854		637·981
	1·559		30·875	
60·18		62·413		668·856
	1·579		31·689	
60·68		63·992		700·545
	1·599		32·513	
61·18		65·591		733·058
	1·619		33·347	
61·68		67·210		766·405

BANGALORE WATER-SUPPLY.

THE distinctive feature of the Bangalore water-works is the method adopted for collecting the supply from the gathering grounds. A description of this, and of such constructive details of interest as occur in the impounding reservoir itself and its feeding and distributary channels, will be given in the following brief memoir.

2. The water-works were designed to supply 10 gallons of water per diem per head to a population of 80,000. The last census of the Bangalore Cantonment gave a population of nearly 60,000 (the scheme does not profess to deal with the Pettah of Bangalore). An increase of 33 per cent. on this number was allowed for, and a supply of 10 gallons per head per diem was considered sufficient, part of the population being already fairly supplied from severa small tanks crossing the valleys along the slopes of which the cantonment is built.

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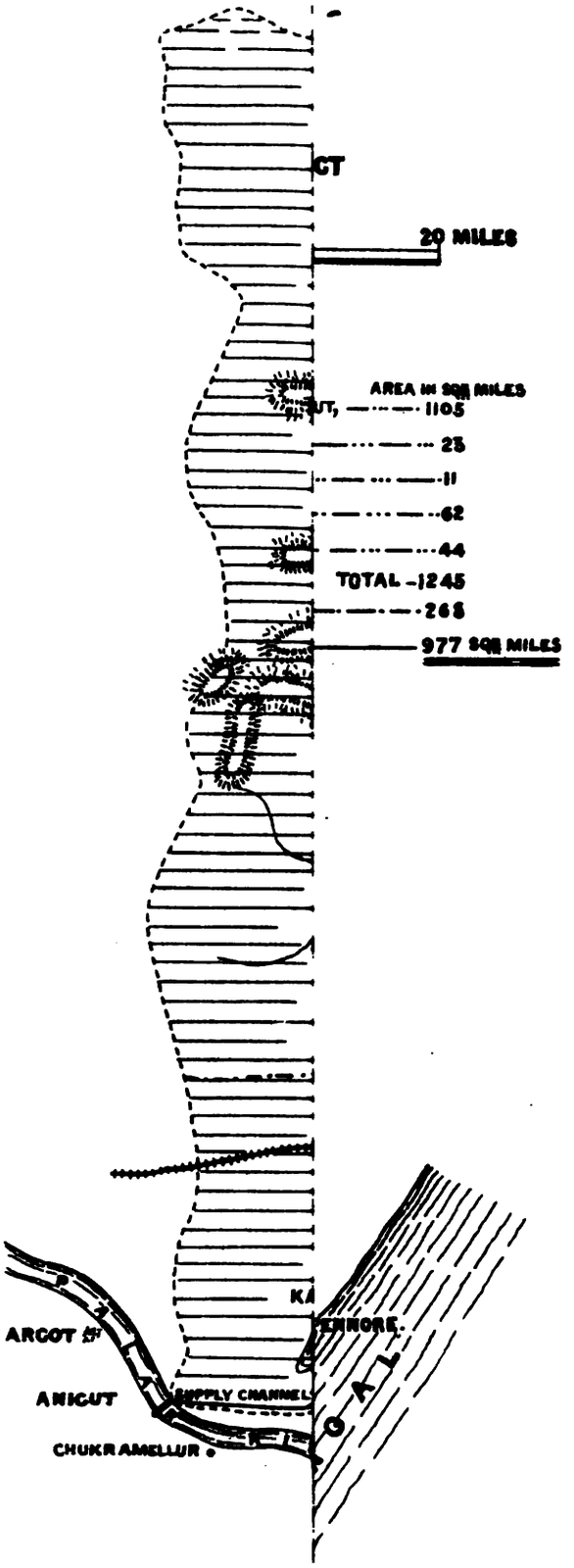
PLATE 1.



Office of the ch(Sd.) Cameron
for
Chepaul

For Chief Engr. for Irrigation.

ED AT THE SURVEY OF INDIA OFFICES, CALCUTTA, JUNE 1880.

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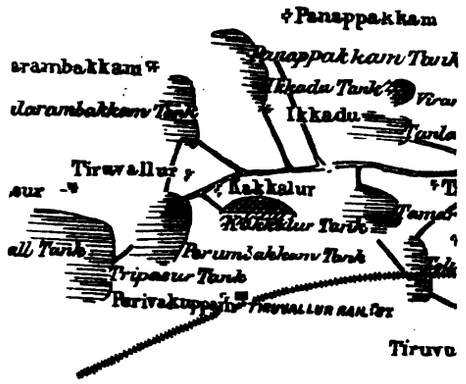

(Sd)

Chief Engineer for Irrigation

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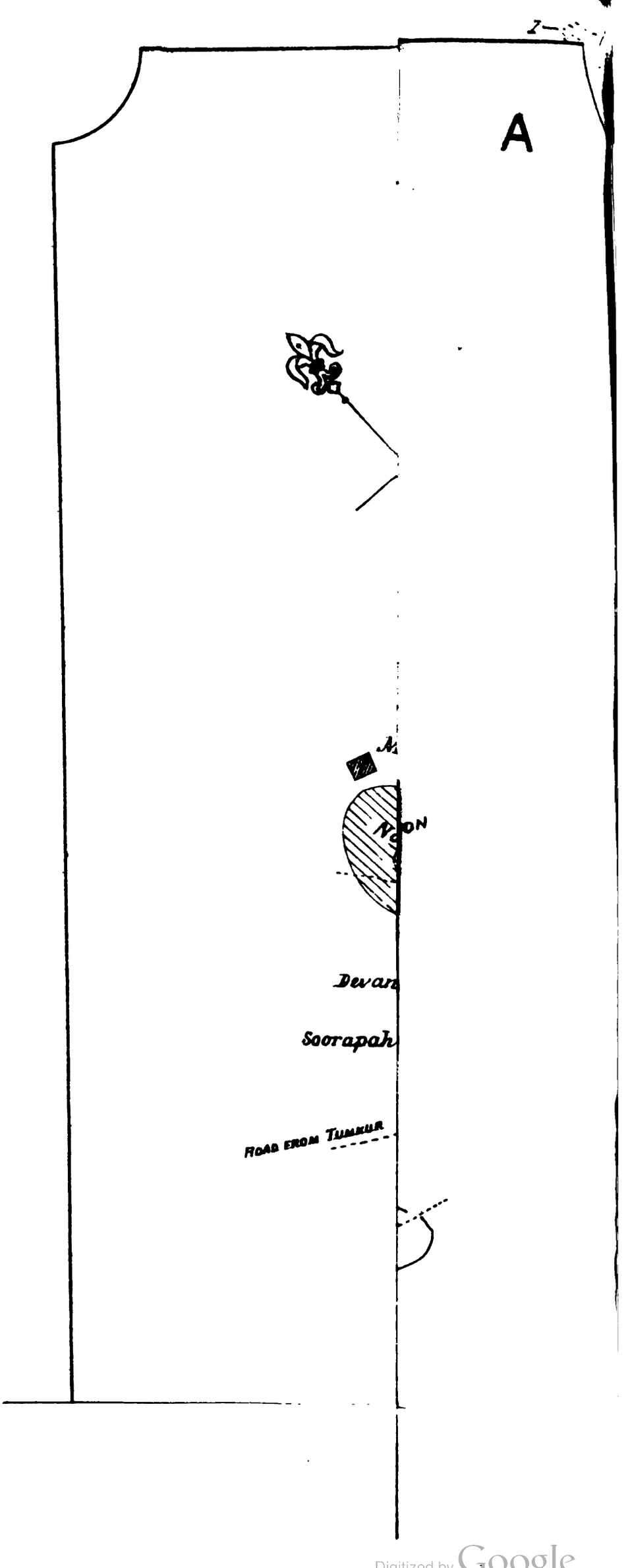

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7. The concrete is composed approximately of one part of mortar (containing one of quick-lime, one of surki, and three of sand) to $\frac{3}{4}$ parts of gravel and $1\frac{3}{4}$ parts of broken stone. The ingredients of the mortar were thoroughly mixed and ground together in a steam-mill, the mixing of the mortar with the other aggregates being performed afterwards by hand. The concrete was used fresh, well-rammed, and kept constantly wet *pari passu* with the concrete wall the earthen bund was carried up on both sides. Tramways were largely resorted to, to save labour, and the earth, excepting the filling immediately adjoining the concrete, was neither rammed nor watered; from its loose, friable character it would have benefited but little from these operations, and the concrete wall was of itself considered a sufficient safeguard against leakage. After completion of the bund, and on the tank filling, extensive leakage was, indeed, observed; this, however, materially decreased as the water level fell, and no danger is now apprehended. It is probable that the greater part of the filtration is through the disintegrated rock underneath the concrete hearting. A section of the bund at centre is given in Drawing B.

8. The inner slope, instead of being protected with the ordinary hand-packed boulders, or dry stone set on edge, is above lowest water-mark, covered with long thin slabs of what is locally known as "burnt stone"—an expression derived from the method of quarrying the schistose rock of Mysore, by kindling over the surface small fires, which split off the upper-exposed layers. The slabs are laid flat in horizontal lines, and the ends break joint in the vertical

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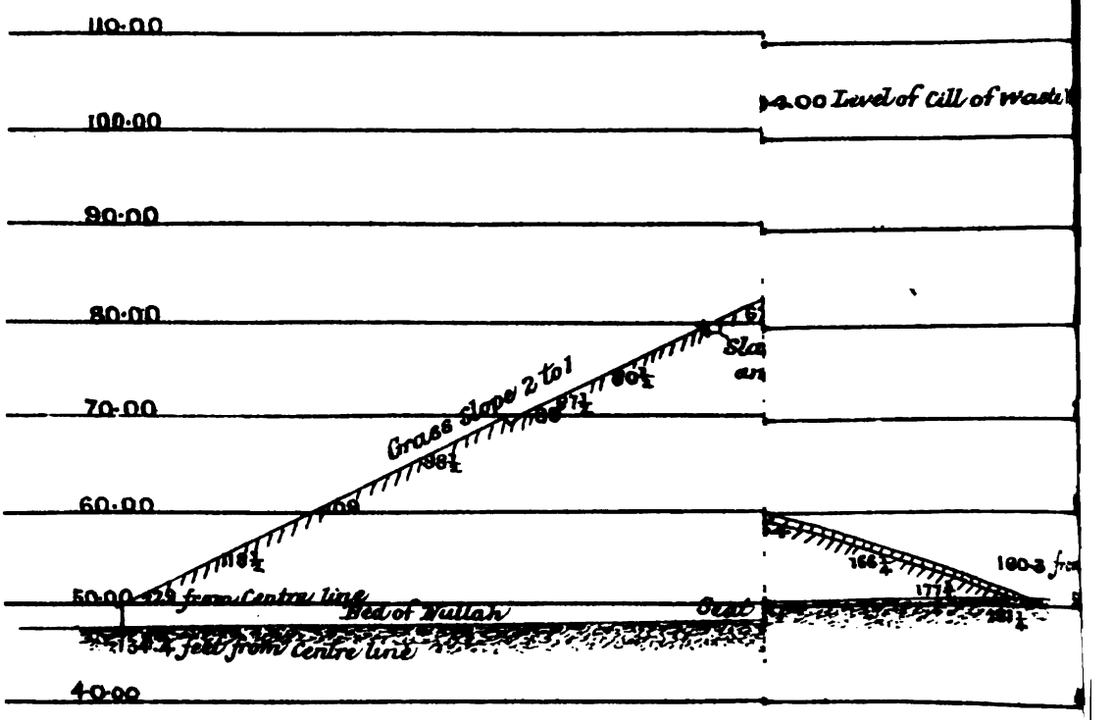
I—52—

A

I. 53—

B



Lieutt. Colonel

Mysore

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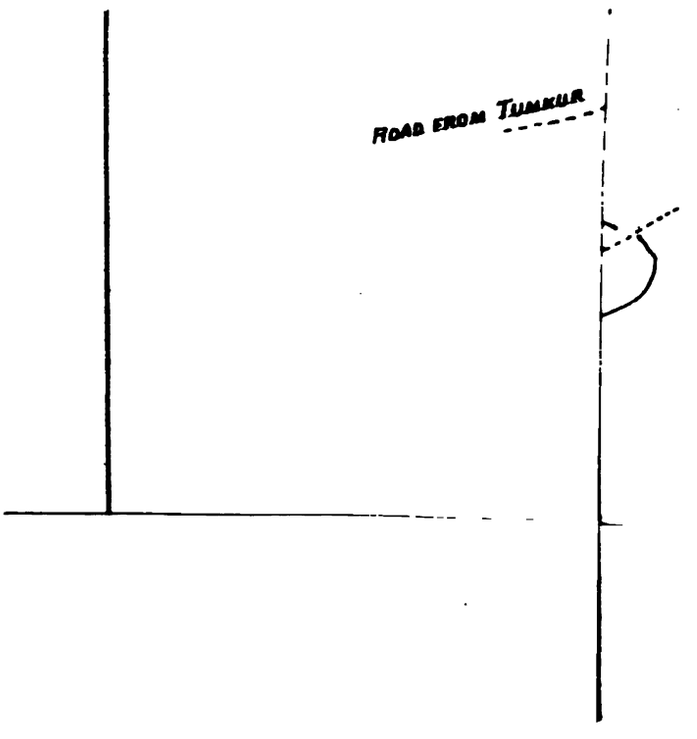
CALCUTTA, APRIL 1869.



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3. To provide the above quantity, amounting to 800,000 gallons per diem, or nearly 47 millions cubic feet per annum, 2½ square miles of catchment were calculated to be ample, the average annual rainfall being 35·7 inches, and the run-off being taken at 37 per cent. of the fall. The most suitable gathering grounds in the near neighbourhood of the cantonment were found to the north-west of the station and encircling the Muntapum Hill, the most elevated point for many miles around. Their general level, in view to a supply by gravitation, was favourable; they not only afforded the requisite area of 2½ square miles, but admitted of considerable extension in the future, and comprised mostly unculturable or poor land.

4. The site selected for the impounding reservoir is immediately west of the above-mentioned hill, and near the head of a valley which drains down south to the Bangalore Pettah. This site, whilst it has sufficient height above the area to be supplied, and is itself commanded by the gathering grounds, has the advantage of affording the requisite storage capacity with a small water surface, but considerable depth, thereby ensuring a minimum loss by evaporation and soakage.

5. The natural direct drainage into the reservoir constructed at the site is but trifling; the gathering grounds lie around and above it, being in fact those portions of the adjoining valleys lying at sufficiently high a level to be drained into the reservoir by intercepting counter-channels. Two such channels branching out right and left from the reservoir bund about weir level, would, it is evident, catch up and convey to the tank the drainage of the whole area embraced by them. Their slope and section would, however, have to be adjusted to the drainage area intercepted, and it is in the disposition of these channels we have the distinctive feature of the Bangalore scheme. The more rapid the fall in two such channels as those adverted to, the smaller the section required, but the greater the available drainage area lost; and on the other hand channels of gentler declivity, whilst embracing more ground, muss necessarily have a large sectional area and lower velocity, entailing thereby greater loss by evaporation and absorption. These two alternative evils are counteracted by the system adopted:—sets of catchment channels are run out from the tank, the lowest to embrace the contour line near weir level, the others at higher levels; in other words, each main channel on either side is sub-divided into a series of subsidiary channels; the inclination or fall of the lower of a series is made small, so that the largest available area is embraced, that of the upper channels of a series being made steeper, so as to obtain a quick delivery of the rainfall on the contained area. Further, in each case the fall is, as far as possible, adapted to the cohesive power of the soil traversed, so as to avoid erosion and consequent silting up of the tank. The surface of the gathering grounds is thus scored over with a number of channels of varying sections and falls, which catch up the smallest shower and deliver it into the tank with a minimum of loss. The accompanying Plan A fully illustrates the arrangement.

6. The section adopted for the bund of the impounding reservoir has a top width of 21 feet, a road being carried over it,—front slope of 1 vertical to 3 horizontal; rear slope 1 vertical to 2 horizontal. The only material available for the body of the bund was of bad quality and unretentive; and clay for puddle not being obtainable, except at a prohibitive cost, it was determined to adopt a cone of hydraulic concrete running through the entire length of the work instead of the ordinary puddle wall. This concrete wall, which at the deepest point has a top width of 3 feet and bottom width of 14 feet, is carried down to firm rock in centre of bund and to firm soil near the flanks.

7. The concrete is composed approximately of one part of mortar (containing one of quick-lime, one of surki, and three of sand) to ¾ parts of gravel and 1¾ parts of broken stone. The ingredients of the mortar were thoroughly mixed and ground together in a steam-mill, the mixing of the mortar with the other aggregates being performed afterwards by hand. The concrete was used fresh, well-rammed, and kept constantly wet *pari passu* with the concrete wall the earthen bund was carried up on both sides. Tramways were largely resorted to, to save labour, and the earth, excepting the filling immediately adjoining the concrete, was neither rammed nor watered; from its loose, friable character it would have benefited but little from these operations, and the concrete wall was of itself considered a sufficient safeguard against leakage. After completion of the bund, and on the tank filling, extensive leakage was, indeed, observed; this, however, materially decreased as the water level fell, and no danger is now apprehended. It is probable that the greater part of the filtration is through the disintegrated rock underneath the concrete hearting. A section of the bund at centre is given in Drawing B.

8. The inner slope, instead of being protected with the ordinary hand-packed boulders, or dry stone set on edge, is above lowest water-mark, covered with long thin slabs of what is locally known as "burnt stone"—an expression derived from the method of quarrying the schistose rock of Mysore, by kindling over the surface small fires, which split off the upper-exposed layers. The slabs are laid flat in horizontal lines, and the ends break joint in the vertical

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plane. They form a neat and efficient covering (though distortion of the surface may possibly occur hereafter from settlement), and owing to the proximity of the quarries they were somewhat cheaper than a facing of either boulders or stone on edge would have been. The rear slope has been grassed; and to prevent its being cut into gullies by rain-water coursing down the long steep surface, paved catchwater drains have been formed along it, discharging into the cistern behind the sluice culvert.

9. The escapes—of which there are two, each 40 feet in length—have high vertical falls, and are provided with wide and deep water-cushions to break the impact from the overflow. The body walls and wings are built with [illegible] rubble facing, backed up by well-

heavy traffic. But, as already stated, the test of time has yet to be undergone. (Drawing E shows the bridge.)

14. After clearing the aqueduct, the delivery channel has to pass in a tunnel or covered way through the Orparhalli Ridge adverted to in paragraph 11. The deep narrow cutting at this point, through hard primary rock, has proved a tedious business, the primitive hand jumper and blasting powder only being used. This barrier once passed, the water will be merely dropped into the tanks at the head of the cantonment bazaar. Financial considerations render it inexpedient for the present to carry out in its integrity the scheme of distribution as sanctioned. Nor is it intended now to construct the store and filter basins provided in the estimate, nor the storm moderator tanks along the catchment channels.

15. The most difficult part of the whole work was undoubtedly the excavation of the deep concrete trench for bund through loose soil charged with water. The operation was, from the character of the soil, attended with great risk, and was unhappily not carried out without loss of life, notwithstanding every precaution. In one case where the excavation had reached

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I. 47

PLATE I.

SURVEY OF INDIA OFFICE, CALCUTTA, SEPTEMBER 1881

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a depth of 25 feet and the sides had for safety been sloped back to a considerable angle, the width of trench not admitting of shoring, a heavy slip occurred after a night's rain, without the slightest previous warning, burying two men and severely injuring three others. In another instance the mere tamping of the concrete at bottom of trench induced a slip, which inflicted such injury on the man tamping, that he died soon after. In such situations the constant presence of danger and the necessity for extreme precaution and watchfulness cannot be too strongly impressed on all concerned.

16. The estimated cost of the scheme was ₹5,49,324, and the cost of work to date has been ₹5,15,074, notwithstanding the omission of store-basins, mains, and their furniture, &c. The "excavation and filling" was under-estimated in quantity to the extent of nearly 50 per cent., the trench excavations having proved much heavier than was expected, owing to heavy slips due to the damp sub-soil. And the average rate of execution for the various items falling under this sub-head was 2 annas 11 pie per cubic yard against 2 annas 7 pie of the estimate. For the same reason the concrete hearting to bund was also exceeded in quantity by about 50 per cent., and the average rate for this material in the hearting and subsidiary works proved to be 2 annas 7 pie per cubic foot against 2 annas 4 pie estimated. How far these excesses would have been compensated under other items, had the scheme been carried out to completion, it is impossible now to say; but it may be maintained that the item of 5 per cent. on the estimate for contingencies has so far been entirely untouched.

OOTACAMUND WATER-SUPPLY.

By Major J. L. L. Morant, R.E., *Executive Engineer.*

Preliminary.—Prior to the year 1866 the water-supply to the town of Ootacamund was of a very primitive nature, being derived chiefly from perennial springs, and shallow private wells. The springs gradually lessened from the universal planting of Australian trees, the extensive roots of which sucked up the water. It has also been presumed that the annual rainfall decreased, though statistics do not exist to prove it. In 1867 these springs were estimated to yield only one-eighth of what they had supplied in 1860. In the year 1866 the Government of Madras called for a water-supply report, which led to the preparation of a project for supplying the Native town of Ootacamund with water. This project, which was sanctioned in 1868, consisted of two parts; one the supply of the bazars, public buildings, and private residences north of the Ootacamund lake; the other, the supply of nearly all the private houses south of the lake. Both objects were partially effected by the construction of two reservoirs, one for each supply. These were completed in 1870.

North and South supplies.—The northern reservoir holds nearly 50 millions of gallons of water, gathered from a drainage basin of 260 acres; the southern only 3 millions of gallons with a drainage basin of 184 acres. From either reservoir the water is carried in open channels cut out of the hill side to the Native town and European houses. The northern channel is four, and the southern five, miles long. The site of the southern reservoir has been ill-selected: had it been made large enough to hold 30 millions instead of 3 millions of gallons of water, it would have more than filled, the rainfall on Dodabetta, near which this reservoir is situated, being double that of Ootacamund. The choice of its site is practically unlimited, as it much more than commands the highest house it has to supply. A detailed description of the largest reservoir and of its supply channel will suffice, as the two are in most respects similar.

Northern Reservoir dam.—The Northern or Marliamund reservoir is formed by a dam 50 feet high at its highest point, 360 feet long and 25 feet wide at top, with inner and outer slopes of 2 to 1. The top of the dam is 8 feet above full reservoir level. The inner slope of the dam is pitched with stone laid as in *fig. 1, plate* I; the stones should have been laid as in *fig. 2, plate* I, with the joints of the stone at right angles to the slope.

In the former plan the water, agitated by winds, washes in between the joints of stone, and washes out some of the earth backing, causing the earthen slope and the stone pitching along with it to settle down irregularly. In the latter plan this is almost impossible, as will be seen by the arrows.

Rainfall, number of days for which water must be supplied.—This dam impounds 46,480,000 gallons of water from a catchment basin of 260 acres. It has usually filled and surplused annually; but in 1875 the depth of water above the supply pipe did not exceed 15 feet, and in 1876 only reached 9 feet, the depth when the reservoir is full being 19¼ feet. When

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he Marliamund reservoir was designed and executed, it was anticipated that it would be only necessary to provide for 60 continuously rainy days, and for the least annual rainfall of 36 inches: but in 1876 the rainfall was only 25 inches, and the number of continuously rainless days for which water must be supplied 304. Even in an ordinary year water for 152 days would have to be provided. The following table of the monthly and annual rainfall of Ootacamund for the years 1869 to 1876 inclusive gives reliable information :—

Years.	Annual Rainfall.			October Rainfall.			November Rainfall.			Total of October and November Rainfall.	
	Rainfall.	Rainy days.	Average fall of rainy days.	October rainfall.	Rainy days.	Average fall of rainy days.	November rainfall.	Rainy days.	Average fall of rainy days.	Rainfall.	Rainy days.
1869 . .	38·65	117	0·33	3·97	12	0·33	3·28	13	0·25	7·25	25
1870 . .	41·92	122	0·34	10·10	15	0·67	1·69	10	0·17	11·79	25
1871 . .	54·92	94	0·58	10·45	12	0·87	13·92	10	1·39	24·37	22
1872 . .	45·42	119	0·38	3·99	11	0·36	6·93	18	0·38	10·92	29
1873 . .	45·41	138	0·33	7·32	23	0·32	2·35	10	0·23	9·67	33
1874 . .	47·48	141	0·34	10·24	20	0·51	2·10	10	0·21	12·34	30
1875 . .	38·45	107	0·36	8·33	19	0·44	2·30	7	0·33	10·63	26
1876 . .	25·16	76	0·33	1·66	8	0·21	0·26	2	0·13	1·92	10
	337·41	914	2·99	56·06	120	3·71	32·83	80	3·09	88·89	200
Average .	42·18	114	0·37	7·01	15	0·46	4·10	10	0·38	11·11	25

From the above statistics it would appear that a rainfall of 12 inches in October and November are about sufficient to ensure an adequate supply to this reservoir. The average of the last eight years gives 11·11 inches. In some years it has filled to overflowing; in others it has not filled at all.

Reservoir waste weir.—The arrangements for the discharge of surplus in the Marliamund reservoir are inadequate: in 1871 and again in 1877 the dam was in some danger from this cause, as well as from the presence of considerable springs at the outer toe of the dam. The escape weir starts at full reservoir level, and allows the water to run through a masonry-lined channel 8 feet wide with no bed fall for a distance of 292 feet, to a series of steps, at the foot of which it is conducted by an earthen channel along the hill side to a safe distance from the bund. The Chief Engineer for Irrigation has reported that the escape channel should be 20 feet wide, to ensure the water never rising over 3 feet above full reservoir level.

How water is drawn off from reservoir.—The water is drawn off from the reservoir through an inlet tower by a double line of 8-inch iron piping laid at one extremity of the dam in the solid ground with a packing of puddle. These pipes are inaccessible, and are very likely to give trouble at some future date. They should have been laid on the floor of a masonry tunnel connected with the inlet tower and carried across the bund to the outlet; the tunnel being made large enough to admit a man: the pipes could then at any time be inspected, and attended to without endangering the safety of the dam.

The reservoir water is drawn off within every 6 feet of its surface (as the water level falls by being reduced) by means of a wrought-iron standard inserted in the inlet tower (*see Plate II*): the standard is provided with four doors at different levels. Each door being lifted by a rod ending with a chain winding round a drum, according to the sketch in *Plate II.* These valves have been found to admit too much water and are not easily raised. Their form does not admit of any improvement being introduced. They should have been slide valves faced with brass, and worked by a rack and pinion.

How reservoir is emptied.—The water on leaving the reservoir runs for some distance in a masonry-lined channel built in a cut on the steep hill side; the channel has been floored and lined with brickwork to prevent leakage so close to the reservoir dam. At the extremity of this conduit and at right angles to it, a masonry stepped drop of the accompanying longitudinal section (*Fig. I, Plate III*), and 5 feet wide has been built, in order at times to admit of the reservoir water being rapidly but safely drawn off. The entrance to this drop is closed

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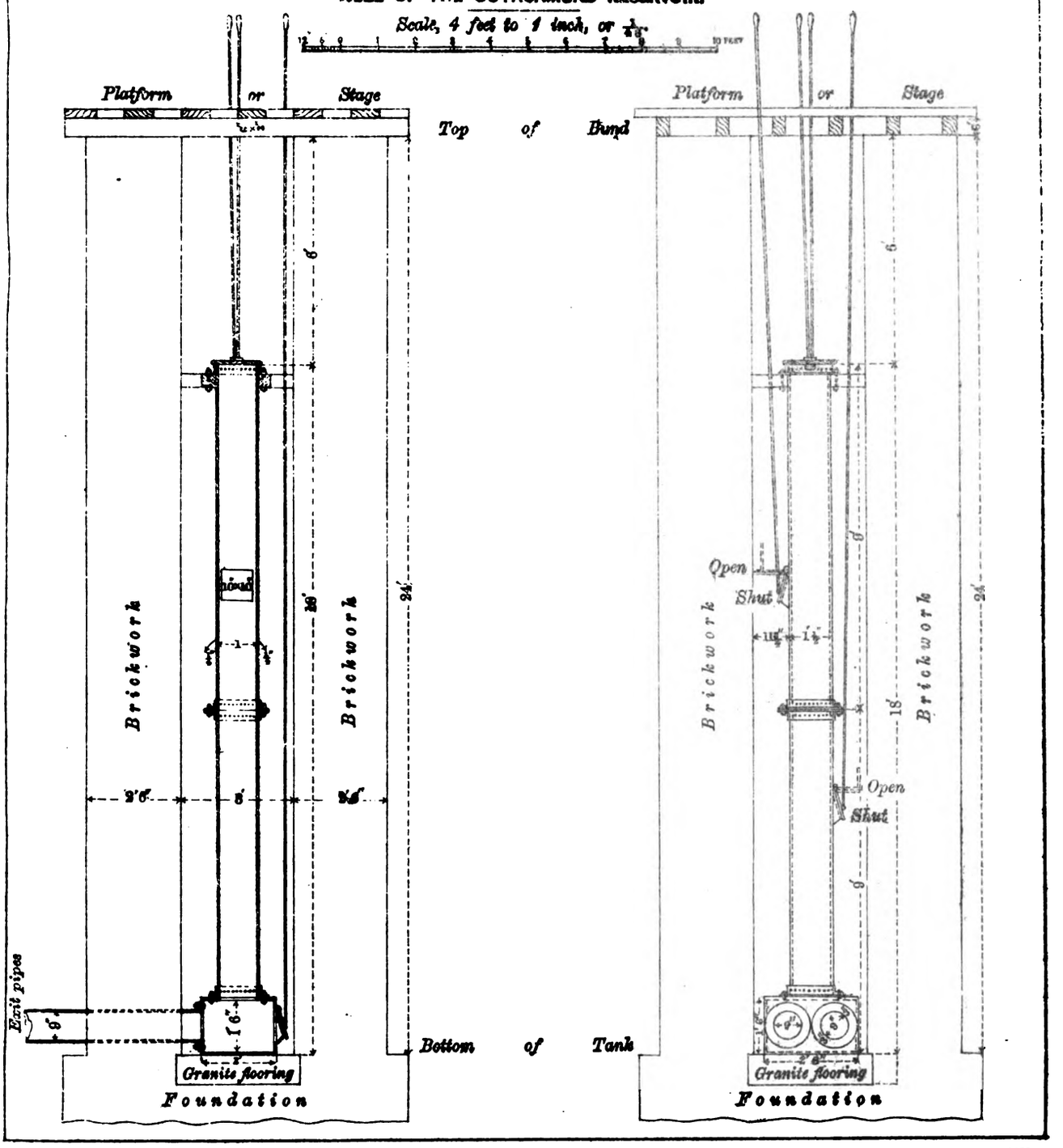
PLATE D.

OOTACAMUND WATER SUPPLY.

SECTIONS OF WROUGHT-IRON STANDARD IN THE INLET WELL OF THE OOTACAMUND RESERVOIR.

Scale, 4 feet to 1 inch, or $\frac{1}{48}$.



LITHOGRAPHED AT THE SURVEY OF INDIA OFFICE, CALCUTTA, SEPTEMBER 1868.

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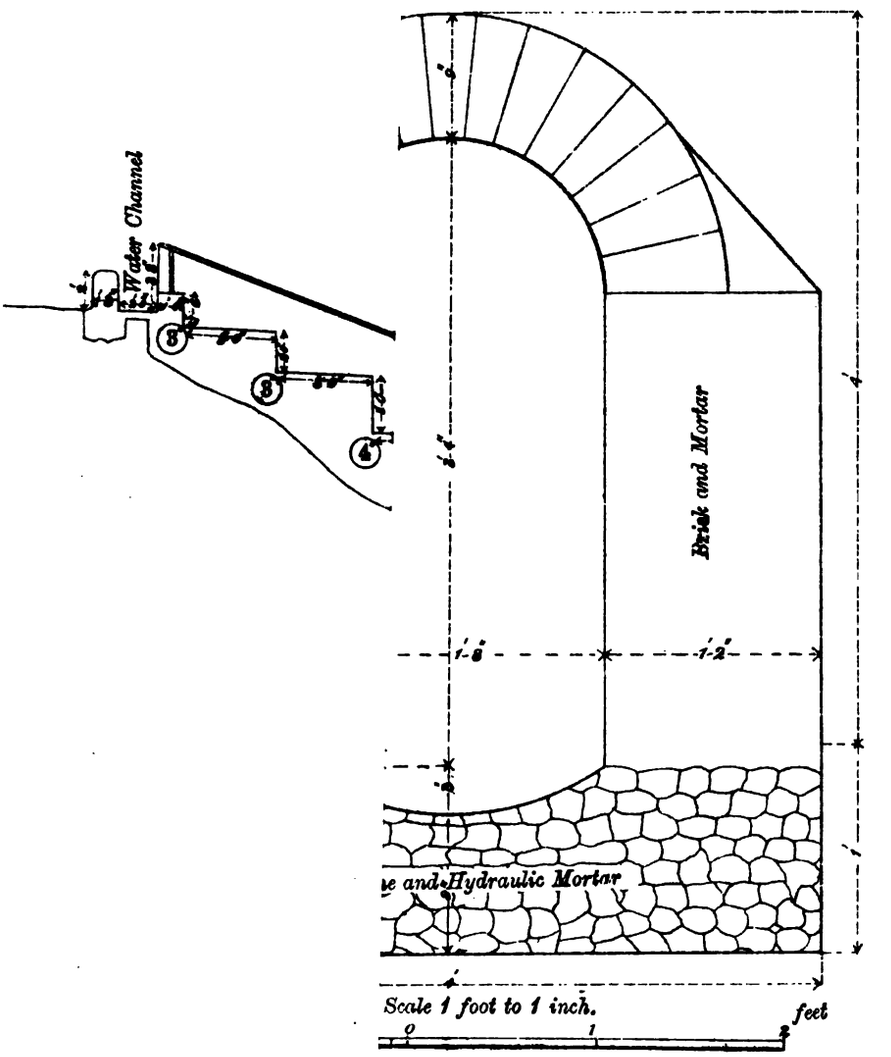
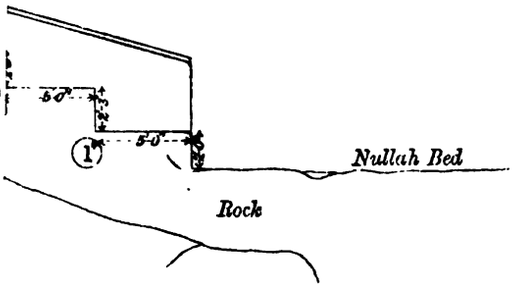
PLATE III.

FIG. 2.

LINING TO SNOWDON TUNNEL.



Width, 5'
Total Fall, 50' 6"
Figures in black, thus



DRAWN AT THE SURVEY OF INDIA OFFICES, CALCUTTA, SEPTEMBER 1868.

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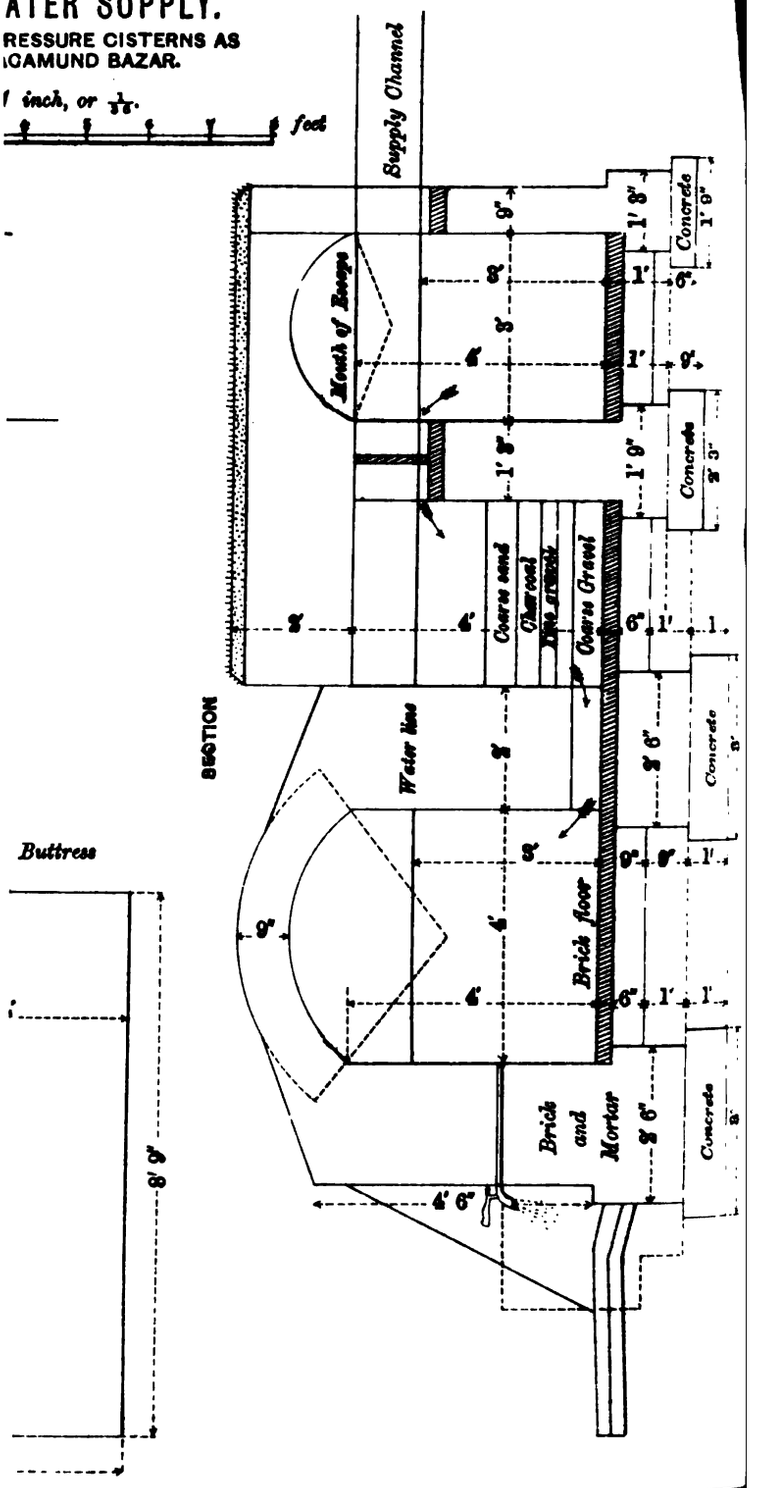
ATER SUPPLY.

RESSURE CISTERNS AS
GAMUND BAZAR.

1 inch, or $\frac{1}{96}$.

feet



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by a teak wood shutter shod with iron sliding in stone grooves. The steps in the drop are sloped backwards to furnish a small water cushion to assist in breaking the fall of water. This method has been found to answer, and the water is safely landed in considerable volume on to a large sheet of rock in the bed of the stream below the dam and quite clear of its outer toe.

Snowdon Tunnel.—The water after passing the drop runs along an open channel cut in the soil for a distance of 1,580 yards, with a fall of only 1¾ feet per mile to the Snowdon tunnel. This tunnel was cut through a mass of earth and rock abounding with springs, by a small party of Native Madras Sappers in the course of 8 months: the party divided into two sets began simultaneously at both extremities of the tunnel and met accurately about midway. Light rails were laid as the work proceeded, and a small truck on wheels hauled by a rope carried out the excavated soil and rock. Gunpowder in water-tight tin cases and Bickford's fuze were used to blast the rocks. The excavation as it proceeded was supported by a wooden casing in the usual way. The tunnel is 350 feet long, and has a total fall of 1½ feet. It is lined with brickwork, &c., of the adjoining section, *Fig. 2, Plate III.*

Supply channel and Bazar cisterns.—From the tunnel the open channel cut in the soil continues for 1,992 yards with a fall of 7 feet per mile to near the Old Church. Here it falls 40 feet down a masonry stepped drop of a section similar to the drop already described in page 4. This drop was built 8 years ago, and has never since been repaired. The water then passes through the Church compound in an open brick-lined channel, whence it is piped for a distance of 960 yards with earthenware pipes (steeped in boiling tar before being laid) surrounded by clay puddle, to the Hospital. It then runs in another stretch of open channel to the town abattoirs, whence it is piped for a distance of 700 yards all through the Native town, feeding three small supply cisterns of the adjoining shape, size and dimensions, *Plate* IV.

Existing water supply incomplete and unsatisfactory.—The water supply to the town of Ootacamund cannot be said to be complete or satisfactory.

Water supply insufficient: proposals for increasing it.—In the first place the information supplied in page 2 will have prepared us to accept the statement that the water already stored is barely sufficient to meet even ordinary demands, while to tide over years of drought it altogether fails: the Marliamund reservoir did not nearly fill in 1875, and did not half fill in 1876.

The daily supply required for the North branch is 300,000 gallons every 24 hours. For 152 days the total supply will therefore become 45,600,000 gallons: while for 304 days it will become 91,200,000 gallons. The Marliamund reservoir holds 46,480,000 gallons. We have here for convenience omitted all account of evaporation from the water surface of the reservoir during the long consecutive periods of 5 and 10 months. To meet the demand in years of drought, other sites for reservoirs are available, though none are so good as the Marliamund reservoir, 300 acres of catchment basin, all well above risk of pollution, and 210 acres at a lower level, and in some respects in a more convenient situation, but below several houses, the drainage from which will pass into their reservoir, can be utilized. A project for a reservoir with dam, inlet, tower, &c., complete at Snowdon House was drawn up in full detail, and has been sanctioned by Government. Its catchment basin is 60 acres; its capacity over 24 millions of gallons of water (with a waterspread of 220,319 square feet, and a mean depth of 17½ feet); the maximum height of its dam was to have been 56 feet, and depth of water at outlet pipe 40 feet; its full reservoir level was to have been 15 feet above the sill of the south face of the Snowdon tunnel, the water from the existing Marliamund reservoir, which passes through that tunnel, being conveyed across the bed of the Snowdon reservoir direct to the filter beds, and thus altogether independent of the level of the water in the Snowdon reservoir. For cost, *see* pages . and .

The water supplied undrinkable.—*Secondly*, the water supply is undrinkable. Almost the whole of the gathering ground of the Marliamund reservoir, the slopes of which are steep, is under cultivation, and is periodically manured. some of this cultivation was begun after the reservoir was formed. The whole of the extensive premises of the Tudor Hall Farm drain into the reservoir. Hence even before leaving the reservoir its water is considerably polluted, and is now of a dark unclean color. When the Marliamund dam was about to be constructed, the water of its ravine was chemically examined, and found to be most remarkably pure: purer than the water in Loch Katrine. An analysis of the water now in the reservoir is as follows:—

	Total.
Solids, grains per gallon	5·25
Volatile „ „	1·75
Sodium chloride, grains per gallon	1·5

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	Total.
Hardness, Clark's scale	0·6
Organic matter	
Parts per million	0·32
Nitric acid, estimated as ammonia	
Parts per million	1·5

Sediments of reddish clay and vegetable tissue animal life present.

Nor does the evil end here. The water, after leaving the reservoir, passes along an almost level and open channel cut in the hill side to the Snowdon tunnel. One European house is situated immediately above it, as also a Native hamlet, the drainage and filth of which contaminate, more or less directly, the water. The whole of this section of the channel is freely traversed by roving cattle which foul and injure it. After leaving the tunnel the open channel runs first below and then above the public road, and immediately behind Hillside Cottage and Prospect House. There is also in parts a great deal of cultivated land above the channel. It is thus easily open to pollution, especially near the houses. It then drops down the masonry fall just above the burial ground of St. Stephen's Church, and passes along a short tortuous open channel, which runs alongside of a much frequented path, through the Church compound to the southern gate, whence it is piped as far as St. Bartholomew's Hospital. It then runs in another stretch of open channel to the town abattoirs, whence it is piped all through the native town. The branch above St. Stephen's Church to Sylk's Hotel is an open channel cut out of the soil. It runs at the back of most, and immediately below some, of the houses on that side, and is in parts freely used as a latrine.

It will be readily understood, from this description, how unclean the Marliamund water is, and how greatly it must be polluted on its way to the town. In truth it is quite undrinkable. Nor do any Europeans now drink it. There may be a few who use it for their gardens and baths, but their drinking and cooking water is obtained elsewhere. The natives cannot be so particular, having less freedom of choice. If they turn to other sources of supply they are no better off. Hence the contamination of the water supplied by this mode is to them, and indirectly to all, a very serious matter. To the drinking of impure water, far more than to the incomplete drainage of the town, is due the outbreaks of cholera and small-pox, and the general unhealthiness of the native town. Many of the wells scattered about the town have become polluted, an invariable consequence of a rapidly increasing population. And the supply channels which feed the lake (the waters of which are freely drunk by the natives) are contaminated and polluted in every conceivable way almost from their sources. Upon all their banks down to the water's edge have sprung up native hamlets, the inhabitants of which are chiefly washermen, milkmen and gardeners. Clothes (perhaps of persons who have died of infectious diseases) are freely washed in the streams, and the entire drainage of all their houses, cow-sheds and manured land flow freely into them. The filth of the stables of all the carrying agencies and other trades drain into these streams. The Ootacamund lake is indeed little better than a large cesspool, and the filthy state of its water is as much due to the pollution of all its feeders as to the drainage it receives from the bazar. The supply of a drinkable water to the inhabitants of Ootacamund is thus a matter of paramount importance.

The water supplied wasted.—Nor is this contamination and impurity of the Ootacamund water the only evil. The loss by evaporation and soakage (and through leaks caused by rats and other vermin) from the supply running for long distances through an open ditch cut in the natural soil is very great. More than one-half of the water is wasted in this way.

Remedies proposed.—Two remedies have been proposed, and estimates prepared for adopting them. First, to enclose the supply channels with masonry conduits or pipes; and secondly, to filter the water. It has also been suggested that a certain portion of the land within the catchment basin of the reservoirs should be bought up, or, if this be impracticable, that some restrictions be enacted to prevent the wholesale pollution of the stored water which now goes on.

Quantity of water required per head.—In calculating the dimensions of the conduits and pipes, it has been assumed that each person will require 20 gallons of water per diem, that there will be 10,000 persons, Europeans and Natives, to be supplied, and that the waste will be 50 per cent. thus:—

	Gallons daily per one person.
Domestic supply, without baths or closets	12
General baths,	4
Town and trades purpose	4
Unvoidable waste	10
TOTAL	30

Hence the northern supply has been estimated at 300,000 gallons per day of 24 hours.

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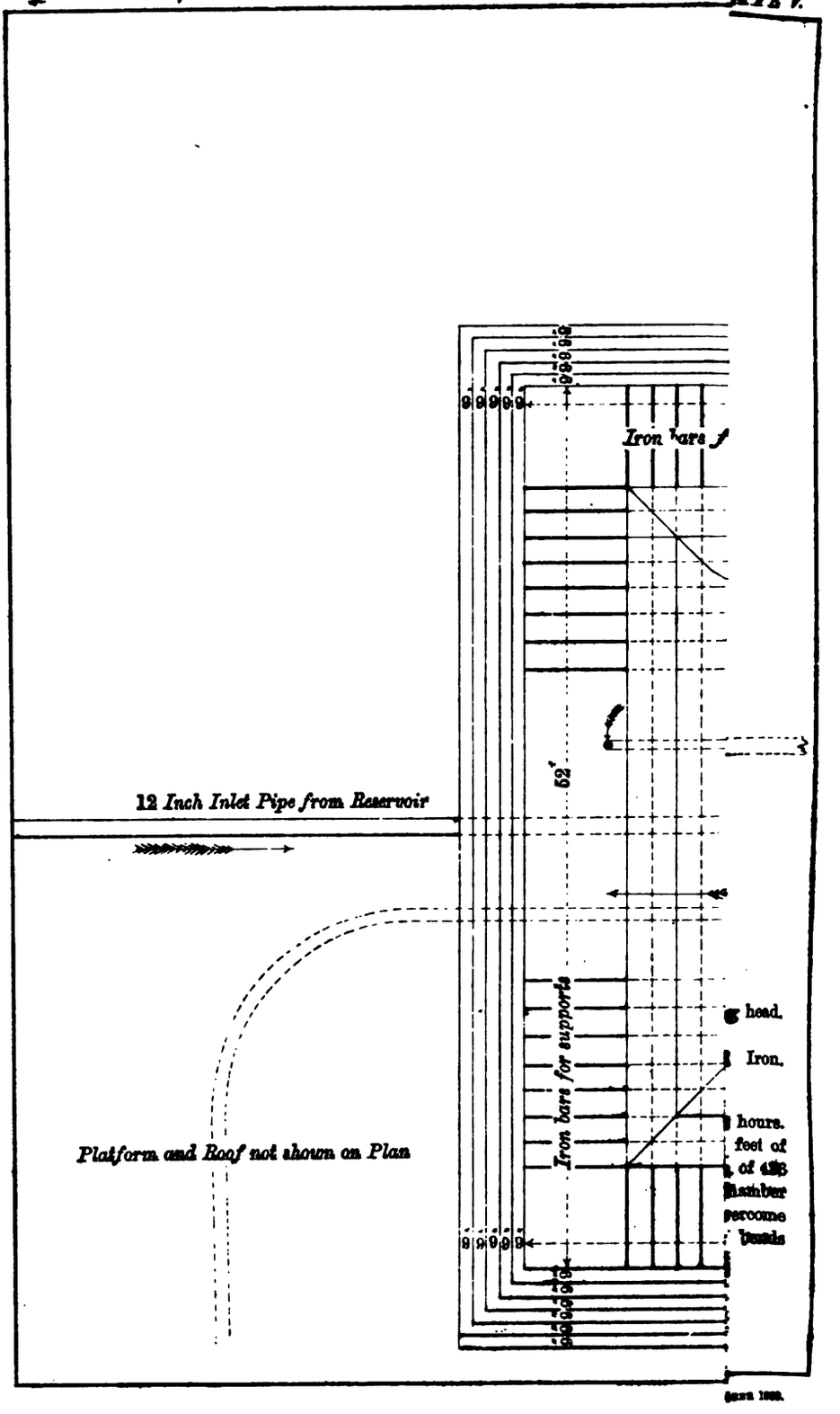
PLATE V.



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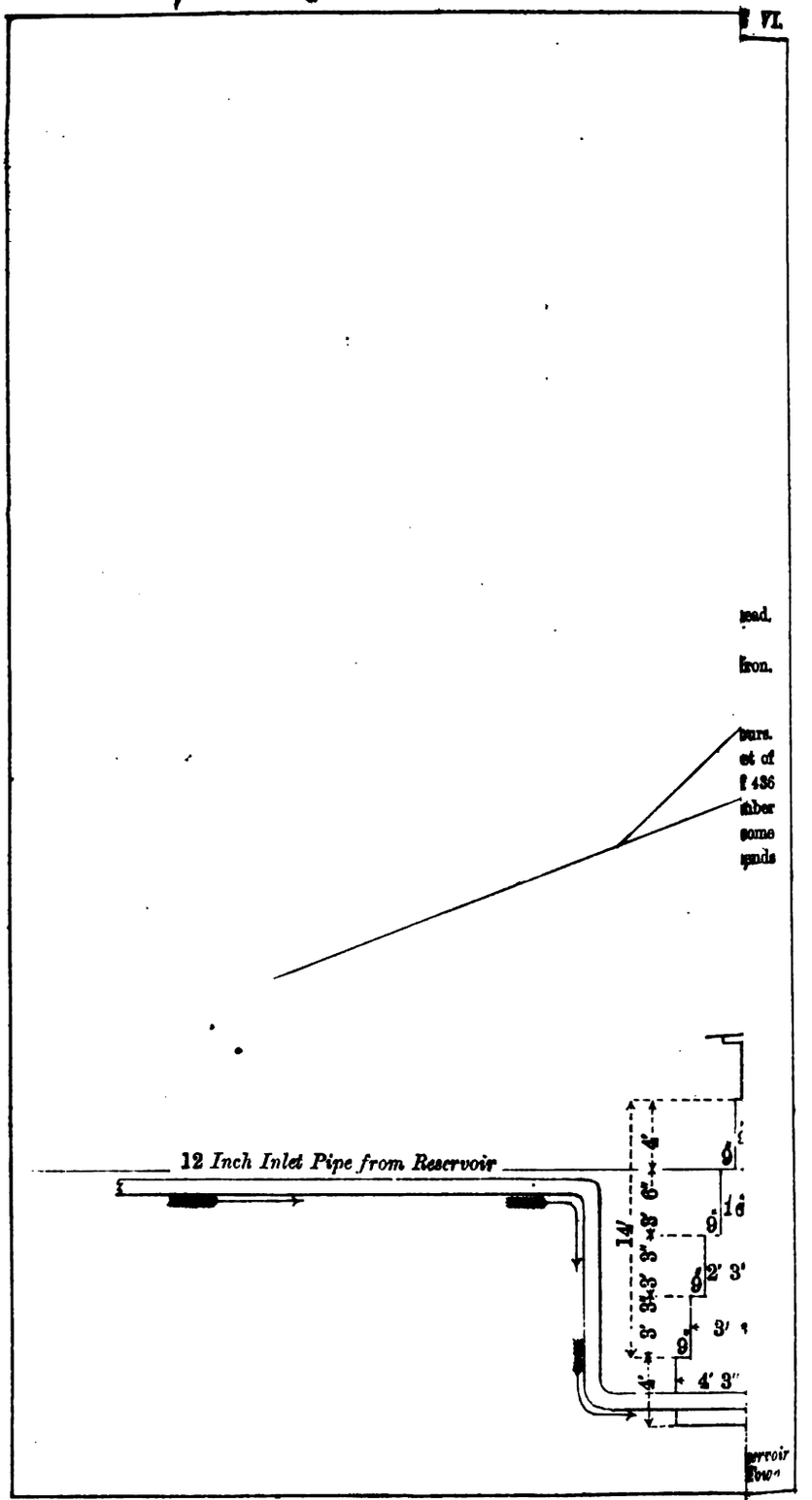
VI.



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Cement piping.—The pipes proposed to be used were, for economy, to be of Morgan's cement of the following size, thickness and price :—

Internal diameter.	Thickness.	Price per running yard, exclusive of rings for junctions.			Cost, including laying, &c.		
Inches.	Inches.	R	*a.*	*p.*	R	*a.*	*p.*
6	¾	1	4	0	1	12	0
10	¾	1	12	6	2	4	0
12	1	2	6	0	2	14	0

The prices in Scotland at ship's side in Glasgow for glazed earthenware pipes are as follows :—

Inches	4	6	9	12	15	18	20	22	24	bore.
Price	*d.* 8½	*d.* 10½	*s. d.* 1 4	*s.* 2	*s* 3	*s.* 4	*s. d.* 5 9	*s. d.* 7 3	*s.* 9	per lineal yard.

General Morgan was prepared to allow his pipes to be subjected to the following tests :—The pipes are to be impermeable, free from cracks or flaws, to ring clearly when struck, and to be uniform in thickness and section. The first test for impermeability is to be :—Each pipe to be dried till it ceases to lose weight, then to be placed in water for 24 hours, and to be re-weighed after having been carefully wiped; the quantity of water absorbed must not exceed 5 per cent. of the weight of the pipe.

The second test is to be :—The pipes to be raised up vertically and filled with water, having a head of 22 feet. The pipes are then to be moderately tapped with a hammer all round, when they should nowhere leak or sweat. Pipes which cannot stand the above tests to be rejected. Great care was to have been taken in effecting the junction of the pipes one with another. For this purpose rings or saddles of cement of a suitable form were to have been provided.

Proposed filtration of the water.—The filtration of the water was proposed to be effected by percolation through animal charcoal. As this method has not been introduced into India, though more economical than the usual process through layers of sand and gravel, I beg to be permitted to detail what has been proposed to, and accepted by, the Commissioners for the town of Ootacamund, though it has not as yet been carried out for lack of funds.

Atkin's animal charcoal.—Vegetable charcoal has been found, not only to be absolutely inert in its action or organic matter in water, but to contain large quantities of salts which are soluble in water, so that the water becomes much harder in passing through it. Animal charcoal on the other hand has been proved to be very effective, and filters water at a more rapid rate than it can be cleansed through sand. A Mr. Atkins, of Chepstow in Monmouthshire, several years ago introduced a method of forming animal charcoal into porous blocks of any required size. The process of manufacture is as follows :—The purest animal charcoal is first reduced to a fine powder, and is then mixed with Norway tar and other combustible materials, also in a state of fine powder. The mass is then kneaded into a plastic condition with liquid pitch, and is afterwards moulded into blocks of the required size and shape.

The moulded blocks are then exposed to great heat, by which means all the combustible ingredients are burnt out, leaving the pure carbon in a solid form. The block is, as a consequence, perfectly porous throughout, the pores being the cavities from whence the combustible material has been burnt out. To clean the block after use, all that is necessary is to wash it in warm water, which removes the organic impurity. If the carbon is used for filtering water containing much salts of lime, a hard incrustation forms on the surface of the block, which is easily removed by scraping when dry. The Ootacamund waters contain little or no lime. Mr. Atkins has by slow degrees improved his invention, and has recently manufactured carbon plates 12 inches square by 2 inches thick, which are set in an iron framing like panes of glass. These frames are fixed vertically, and the water filters horizontally through them. As soon as the surface of these plates becomes encrusted with organic or other matter, the water ceases to pass through, and thus the inert condition of the filtering media is at once indicated.

Proposed animal charcoal filter.—I proposed placing a complete framework of these plates like the four sides of a box, in a rectangular chamber of masonry 95 feet long by 52 feet broad by 10 feet deep (*see Plate V.*) The charcoal framing to be supported by iron bars on an incline of ¼ to 1. In the same chamber, and on the innerside of the charcoal framing, to be fixed a vertical framework of fine copper gauze of 30 meshes to the inch. The supply water to pass through a 12-inch iron pipe into the enclosure formed by the four sides of the gauze framing, through which it will pass horizontally into the space between the gauze and the

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charcoal, through the plates of which it will ooze out horizontally into the outer portion of the masonry chamber, whence it will be carried off by four 6-inch pipes into the main which supplies the town. The centre chamber which the water first enters to be sunk 3 feet below the bottom of the charcoal plates, and to form a large trap (60′ × 18′) for the silt held in suspension by the water: a sluice gate worked from the platform above to be provided to empty this trap and slush out the silt. If thought desirable a double, triple, or even quadruple set of carbon framed plates can be erected in the masonry chamber, and be placed wide enough apart for a man to pass freely between them. In this way the water can be brought to any required degree of purity. I designed a chamber with three sets of carbon plates. The outer portion of the chamber, in which will flow the filtered water, to be covered with a planked floor, from which the charcoal plates can be cleaned by brushes with long handles. Wooden steps to give access to the inner chamber, both it, the intermediate and the outer chamber being provided with slide valves to empty them. A corrugated iron roof to be also provided to preserve the sloping surface of the carbon plates from being injured by hail and rain drops. This iron roof might be omitted for the sake of economy. Dr. Letheby states that water should not be filtered through animal charcoal with greater rapidity than 4 gallons per minute per cubic foot. Atkin's carbon plates filter 200 gallons of water per square foot in 12 hours. This gives a rate of from 2 to 3 gallons per minute per cubic foot. Thus Atkin's carbon plates filter sufficiently slowly. The minimum supply needed for the north of Ootacamund is 300,000 gallons. Therefore 1,500 square feet of filtering surface is needed. The design gives 1,936 square feet, or a margin of 436 square feet, to make up for portions of the charcoal surface being occasionally choked. The capacity of the unfiltered chamber is 13,355 cubic feet, and of the filtered chamber 16,830 cubic feet. The latter is purposely made larger than the former to make up for the additional resistance due to the four exits in lieu of the one entry, and to the larger number of bends in the piping. A silt chamber 10 feet long by 6 feet deep to be built in front of the filter chamber, in order to catch some of the silt held in suspension by the water before it is admitted into the filter. A small chamber in rear of the filter will also indicate the rate at which the water is passing through it. These carbon filters will probably require cleansing not oftener than once a month.

Cost of the water-supply.—The two branches of the Ootacamund water supply have already cost the following sums:—

	R	R
Marliamund reservoir dam complete,	14,544	
The Snowdon tunnel cut out and lined at nearly R20 per foot run	6,400	
The open supply channel some 4 miles long in parts piped, &c.	7,685	
		28,629
South Branch.		
Dodabetta reservoir	4,990	
The Elk Hill Aqueduct	10,393	
The open supply channel	730	
		16,113
TOTAL R	...	44,742
Proposed Expenditure.		
The Snowdon reservoir complete (described in page) sanctioned in Madras Government P. W. G. O. No. 105 W, dated 8th January 1878	...	22,940
The piping and filtering of the water of the North Branch estimated to cost as follows:—		
Piping throughout the North Branch	30,000	
A triple carbon filter with storage reservoir to hold 150,000 gallons	50,000	
		80,000
TOTAL R	...	1,02,940
GRAND TOTAL R	...	1,47,682

Cost of annual repairs to Ootacamund water-supply—

The present cost of the maintenance of the Ootacamund water-supply is as follows for both branches:—

	per mensem. R	per annum. R
1 East Indian Superintendent	30	
4 Coolies, at R8 each	32	
	62	744
Approximate repairs, &c.,	...	250
TOTAL R	...	994

Say R1,000 per annum.

OOTACAMUND;
22nd September 1879.

J. L. L. M.

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DESCRIPTIVE ACCOUNT OF WATER-WORKS, HYDERABAD (SIND).

Preliminary.

The city of Hyderabad, which is looked upon as the Capital of Sind by all the natives of the Province, is situated in latitude 25° 22″, North, and longitude 68° 22″, East.

It is built upon the most northern outcrop of a range of calcareous rock known as "The Ganja Hills," and stands on an isolated plateau, rising from an alluvial plain, separated by about a mile from the general range.

This plateau is divided into two parts by a depression running north and south; on the eastern the city stands at an elevation of 50 feet, and on the western the cantonments at an elevation of 26 feet above the surrounding plain.

The Fuleli, a large inundation canal, flows past at about a mile to the east, and the river Indus about three miles to the west of the city.

The city is connected with the river by a well-metalled road to Gidu Bandar, at which point the present water-supply is drawn off.

By the last census the population of the town is 44,968, and of cantonments, including the Sadar Bazar, 3,141.

The strength of the garrison is as follows:—

	Officers and Men.	Women and Children.	Horses.
One Battery Royal Artillery	148	34	108
Three Companies British Infantry	227	27	...
One Native Infantry Regiment	707	136	...
Total .	1,082	197	108

Former Water-Supply.

The average rainfall at Hyderabad is estimated at 5 inches annually; and as there was no arrangement for collecting or storing it, there was no water procurable on any portion of the cantonment or city plateau.

Formerly, during the inundation season, the supply for the city was drawn from tanks dug in the plain at the eastern foot of the rock; these were supplied from the Fuleli, and were computed to hold 6,100,000 gallons.

On the fall of the inundation the water was dammed up in these tanks, and as they became dry the inhabitants had to depend for their supply on wells sunk in their beds, or in the surrounding plain.

In bad seasons even this supply became brackish, and no good water was then procurable nearer than the Fuleli on one side and the river Indus on the other.

The troops also drew their water from similar tanks: the European from "Jacob's Tank," situated to the north of cantonments, and the Native and Staff from the Belooch tanks on the south-west.

These tanks also were supplied from the Fuleli by a small inundation canal, but all quickly dried up on the subsidence of the inundation. Water was then procured from wells sunk close to the tanks; but this supply always proved scant, often becoming brackish, and in some seasons the scarcity almost amounted to a semi-drought.

Several projects were from time to time mooted for raising water by animal or other power from the Fuleli canal, or the river Indus, even to the low level of the old existing tanks; but no scheme was authoritatively put forward until 1864, when the Municipal Secretary proposed one for supplying the town with 750,000 gallons of water daily, taken from the Indus, at a cost of five lakhs of rupees. This scheme was not sanctioned.

In 1869 it was proposed to pump a supply from wells sunk close to the river, near the new Fuleli head, in the hope that by so doing sweet and clear water would be obtained, equal in quality to that of the Indus, without the further difficulty and cost of building settling tanks; but after the trial-well had been sunk, it was found that the water became brackish on the river falling to its cold weather level.

On the failure of this experiment, the Superintending Engineer, Major-General (then Colonel) Merriman, R.E., in 1870, instructed Mr. Robert Brunton, C.E., the Local Fund Engineer, to make a survey and prepare plans for a project to supply the City and Canton-

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ments with 1,000,000 gallons of water per diem, taken direct from the Indus near Gidu Bandar. Eventually Mr. Brunton's plans were sanctioned, and a loan of Rs. 3,00,000 obtained from Government, and the work was commenced in 1874.

General Description.

The project may be described generally to consist of an arrangement to raise water from the river into two depositing reservoirs, to be filled alternately, each capable of containing 1,500,000 gallons.

This is done by means of a large sized centrifugal pump, and when the water in one reservoir has deposited its silt, and while the other is being filled, it is allowed to run by gravitation through a masonry conduit, 3,813 yards long, to a point where it separates into two branches to supply the cantonments and the city respectively.

The branch to the cantonments is 403 yards long, and ends in a short tunnel and oval well, from which the water is pumped into a reservoir or tank capable of holding 115,500 gallons; whence it flows by gravitation through cast-iron mains laid down to the following points:—

1. Staff Lines to the Collector's Kacheri.
2. Travellers' Bungalow.
3. General Hospital and Armed Police Lines.
4. The European Barracks.
5. The Native Infantry Lines.
6. The Sadar Bázár.
7. The Commissariat Lines.

Along the course of the mains, there are numerous stand-pipes from which water can be drawn without limit.

The troops are supplied by the following services:—

1. A cistern in each European Barrack lavatory.
2. One at each European cook-house.
3. One at the European soldiers' plunge-bath, holding 40,000 gallons (filled weekly).
4. One at the patcherries, where there are two iron tanks to each block.
5. One at the Artillery Horse Lines.
6. One at the Garrison Cells.
7. One at the Station Hospital.
8. One at the Commissariat Bullock Lines.
9. One at the Native Infantry Lines, consisting of eight cocks.

In addition to the above, the Rural and Horse Police lines are each provided with a separate service, and there are eight services among the bungalows in which Military and Civil officers and Government Telegraph officials live, from which the roads and road-side trees are also watered.

Besides the water being palatable, wholesome and pure, which the old supply was not, the quantity now used by the troops is more than three times that supplied under the old system. The daily consumption, which is highest in May, reaches 21·15 gallons per head, and is lowest in January when it falls to 13 gallons per head, thus giving an average daily consumption of 17·25 gallons per head per annum.

The supply to the city is carried through a continuation of the main conduit for 1,210 yards, at which point it was found necessary to tunnel the southern spur of the Cantonment hill for 770 yards, from which, again, a short conduit of 256 yards carries the water into the Shah-Kadam tank, close to the foot of the rock on which the Fort stands.

This tank is capable of containing 1,000,000 gallons, but there is seldom more than 800,000 gallons required in it.

The water is then pumped at a total height of 90 feet into a tank standing in almost the centre of the old Fort of Hyderabad, capable of holding 750,000 gallons, and from it the city supply runs by gravitation—

1st—To the various services in the Main Bazár and side streets.
2nd—Civil Hospital.
3rd—The Markets.
4th—Dharmshála.
5th—Into the District Jail.

There are throughout the city 40 public stand-pipes, consisting of 130 cocks, besides the special service for the Jail with 5 cocks. (See Plate XV.)

There is a 3″ pipe from the tank in the Fort to the Municipal garden which supplies a public fountain, and partly waters the garden.

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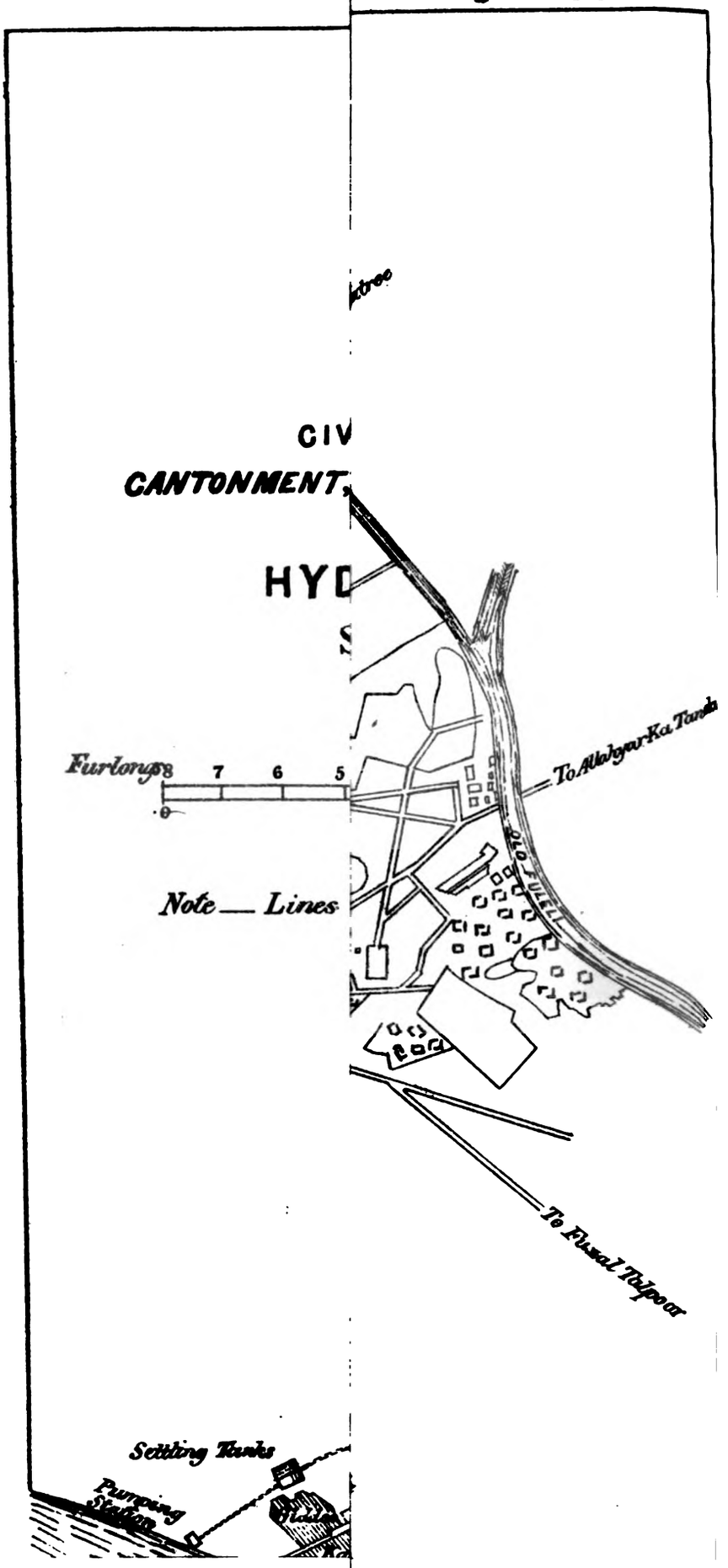

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There are four bullock services with 24 cocks each. (See Plate XVI.)

There are two bathing places for men supplied from a tank, with one large ball-cock. (See plate XVII.)

There is one bathing place for women supplied by 8 small cocks.

There are three drinking troughs for animals, at separate points, supplied by a ball-cock each.

Since the introduction of the water-supply, only 12 families have availed themselves of having a private supply laid on, although the original charge for the stand-pipe is made as low as possible, with a monthly charge for water rate of 8 annas for a ½″ pipe, ₹ 1 for ¾″, and ₹ 3 for a 1″ pipe per mensem.

The daily consumption in the city under all heads is highest in May, when it reaches 5·50 gallons per head; and lowest in January, when it falls to 3·50 gallons per head, thus giving an average daily consumption of 4·50 gallons per head per annum.

It is apparent from the above figures that the consumption of water per head in the city is only about one-fourth of that in cantonments.

This may be partially accounted for by the following circumstances:—(1) About 10,000 of the city inhabitants are of a class of Hindus who have not yet taken to use the water for any purpose. (2) About 2,000 of the towns-people, who live near the Sadar Bazár, always draw their water from the cantonment supply, as do also many of the town bhisties, who supply water for building or other purposes not actually connected with domestic consumption. For pumping operations with consumption of fuel, see Appendix I.

Construction.

In order to give a detailed description of the construction of the works it is necessary to divide them under the following three heads:—

River Lift and Works common to City and Cantonments.

The cost of this portion of the work and working expenses are shown in column A in the Appendices II and III.

Fort Lift and City Works.

The cost of this portion of the work and working expenses are shown in column B, Appendices II and III.

Cantonment Lift and its Works.

The cost of this portion of the work and working expenses are shown in column C, Appendices II and III.

River Lift.

It was first intended to erect the engine and boiler close to the river bank, on large blocks of masonry, sunk considerably below the known lowest level of the river. The first and largest block for the engine and pump was successfully completed, but the sinking of the second block for the boilers was a failure. It was then resolved to carry back the engine and boiler house some 200 feet inland and connect the pump with the river by means of a suction pipe equal to that distance.

The large masonry block near the river was then used to fix a triple sheerlegs upon, which works on a knuckle joint, for the purpose of raising or lowering a portion of the suction pipe. This portion of the suction pipe is fitted on the gyrating principle, with a ball and socket joint, which allows of the pipe being raised or lowered, according as the river rises or falls.

The sheerlegs are connected to the pipe by braces and stays, and the whole is worked by a crabwinch and chain. (See Drawing No. II and Frontispiece.)

The Engine.

The engine is direct acting, and works a centrifugal pump with a four feet disc. The diameter of the steam cylinder is 12 inches with a stroke of 8 inches.

As the river fluctuates, there is a very considerable difference in the speed at which the engine is driven; there being a difference of 18 feet between the high or inundation level of the river and its cold weather level. The greatest lift is 43 feet, and the least 25 feet. When the river is at its lowest, the engine makes 255 revolutions per minute, and when at its highest only 190.

The suction pipe of the pump is 14 inches, and the delivery pipe 12 inches in diameter. Such an arrangement may appear exceptional; but the length of the suction being so great, the object in putting in a 14″ pipe was to reduce friction, and give the pump a full supply of water without straining the engine.

The engine and pump were supplied by Messrs. J. & H. Gwynne and Co., of London, and are of the very best construction, and having no valves or pistons, the wear and tear is reduced to a minimum.

The pump has proved itself the very best which could have been selected for the work it has to do in lifting heavily silted water.

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The water is delivered into an aqueduct, by which it is carried into the depositing reservoirs, which are at a distance from the engine house of 425 yards.

The aqueduct is built on a series of 44 arches of brick masonry on stone piers, and the inside of the channel is plastered with Portland cement. (See Plates Nos. 2 and 3.)

The depositing tanks or reservoirs are built together, and divided down the centre by a solid wall of rubble masonry; they each measure 200′ × 100′ × 13′, and often are charged with as much as a million and-a-half gallons of water, while it is in process of settling before being run off for the city supply. The outer walls are also very solid masonry. The flooring is concrete with brick on edge, and it, together with the walls, are covered with a coat of Portland cement half an inch thick.

It is found necessary to clear the deposited silt from these tanks once in twelve months. The depth of silt deposited in that time is found to average 12 inches. This may be thought to equal a monthly deposit of 1″, but that is not so, as the deposit in the high season is greater, when there is a greater quantity of water pumped in and used than in the cold season. The deposit from each pumping is $\frac{3}{16}$ of an inch; and it is remarkable how clearly each layer of silt can be distinguished when the entire mass at the bottom of the tank is cut through.

There is a low level back sluice fitted to each of these tanks through which it was intended to scour or sluice out the silt, but the deposit was found to be too tenacious to allow of its being treated in that way, and it has to be removed by being dug up and carried out in baskets, just as silt is removed from canals.

From all the tanks silt has to be removed now and again, as the water does not drop it all in the settling tanks, and it even carries with it a very cloudy appearance into domestic use, unless allowed long to settle or is filtered.

Numerous fish are hurled up through the delivery pipes into the various tanks, and they grow to a large size if not removed. For the dimensions of the settling tanks, see Plates Nos. 4 and 5.

Sluice Valves.

The water from each tank is run off into the conduit which carries it to the cantonment and city lifts through an automatic sluice valve. The description of the sluice valve and its mode of construction were very fully given by Mr. R. Brunton in his specification connected with his Patent called "Brunton's Antomatic Sluice Valve." The specification can be obtained at the Office of the Home Department of the Government of India, and is a long and interesting document.

The automatic sluice valves on the Gidu Bandar settling tanks may be shortly described as follows. The apparatus is so arranged that by means of a cam, keyed on to a lever shaft, the outflow of water is regulated to a steady discharge of 4 cubic feet per second at different heads, between 9 feet and 1 foot of water in the tanks. The curve (logarithmic) in the cam is stated by Mr. Brunton to be such that it is most difficult to work out exactly mathematically, but that it can be arrived at geometrically; and there are long descriptions in the Patent specification before alluded to, showing how to construct the cam curve practically, and adjust all the appliances. (See Drawing No. VI.)

The real motive power in working the valve is a buoy, which is so loaded as to give it a certain immersion when resting on the water.

It is attached to the lever by means of a chain hooked on to the "Arch Head" on the *inside* of the reservoir or tank. The valve may be completely shut by means of a crabwinch connected with a chain attached to the "Arch Head" *outside* the reservoir or tank; and the machinery is put in operation and the valve opened by disconnecting the chain from the crabwinch; thus lowering the buoy until it is immersed, from which time the action of the valve is entirely controlled by the cam, which raises the stop-plate, and increases the aperture of discharge as the head of water decreases in the reservoir.

The width of the exit passage is 12 inches, and the depths of the opening at the different heads between 9 feet and 1 foot are as follows:—

At 9 feet	head—	depth of opening	$3\frac{3}{16}$″
„ 8	do.	do.	$3\frac{1}{8}$″
„ 7	do.	do.	$3\frac{11}{16}$″
„ 6	do.	do.	$3\frac{7}{8}$″
„ 5	do.	do.	$4\frac{1}{4}$″
„ 4	do.	do.	$4\frac{7}{8}$″
„ 3	do.	do.	$5\frac{1}{4}$″
„ 2	do.	do.	$6\frac{1}{4}$″
„ 1 foot		do.	$9\frac{1}{4}$″

It can be observed that the size of the apertures relating to the different heads of water vary irregularly, and it is owing to this peculiar irregularity that some of the difficulty is found in obtaining the true curve of the cam.

In practice the valve works well, and owing to its self-regulation, there is no danger whatever of flooding the conduit. This style of sluice would appear to be very suitable to

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regulate the flow of *small* quantities of water from canals, where the working of the apparatus would be under constant technical supervision.

Conduit.

The conduit is built on a foundation of concrete and rubble masonry with brick superstructure. The channel is plastered inside with Portland cement, and closed over with large specially made tiles. These tiles are constantly being broken, and it has been found necessary to replace them by covers made of stone. The greatest depth of water run through the conduit is 19 inches. The conduit is carried across the Wadhu Canal, at 3,150 yards from the river, on a small arch; and at this point there are two waste sluices provided, through which the water can be discharged into the Canal. (See Plate No. VII.)

By this arrangement the settling reservoirs can always be run dry for clearing or other purposes.

There are seven small cisterns built alongside the conduit at intervals of from 100 to 200 yards to supply water to the Gidu Bandar road, water trees, and allow of animals drinking. (See Plate No. VIII.)

Cantonment Lift.

The engine house is built on the highest point of the Cantonment plateau, near St. Thomas' Church (see Plate No. IX). The pumping engine is a 6-horse power, semi-portable, and drives a centrifugal pump, fixed in an oval well which is supplied as before described. The pump has a disc 1 foot 8 inches in diameter and is driven by a belt from the engine. The belts, which are cotton, are excellent, and are made at a very low rate in the Hyderabad Jail. The engine makes 138 revolutions per minute, and the pump 830, but both could be driven at a much higher speed if it was necessary.

The suction and delivery pipes are 4 inches in diameter.

The water is lifted to a height of 52 feet.

The tank is built of very solid rubble masonry, and plastered inside all over with half an inch of Portland cement. (See Plate X.)

City Works.

The portion of this work which appertains to the supply of the City only may be said to commence where the conduit gives off the branch to the cantonments.

Of this portion of the conduit 1,210 yards is in open cutting up to the point at which the tunnel commences, and its construction is exactly the same as the portion which is entirely above ground.

The limestone through which the tunnel is driven is very soft and unstratified. Within the gallery or tunnel a foundation of concrete is laid down on which the conduit is constructed in the same manner as the other portions of the same work. (See Plate No. XI.)

The Shah-Kadam Tank, or the low level city reservoir, is built in a depression close to the Fort. It is supposed that the depression is the remains of a quarry from which materials were removed for the construction of the Fort.

The tank is constructed of strong rubble masonry on rock foundation, with 6″ of concrete and brick on edge in the bottom. (See Plate No. XII.)

This tank being so much below the level of the river suffered from infiltration of brackish water during the inundation, but this was stopped by first having the joints pointed with Portland cement, and then the entire surface of the walls and bottom plastered half inch thick with the same.

The Fort Lift.

(See Plate No. XIII.)

The engine and boiler house is built at the foot of the Fort wall at the west side, 250 feet from the tank above described.

The connection between the pump and the reservoir is made by a 12″ suction pipe.

The engine is horizontal, with a steam cylinder, 17½″ in diameter and 15″ stroke, and is connected to the pump by a spur wheel. The engine makes 5 strokes to 1 of the pump, and the engine is driven at 110 strokes per minute.

The pump is double acting and is 18″ in diameter, and has a stroke of 3 feet.

The ascending main or delivery pipe is 12″ in diameter, and goes upwards through the Fort wall in a diagonal direction, and discharges into a small receiving cistern, just inside the Fort wall. From this is laid down a 15″ pipe to the city supply reservoir (see Plate XIV) in the centre of the Fort, from which the city is supplied as before described.

Together with the frontispiece and 17 plates, which illustrate various portions of the works a map and section are attached, which show the lines of the conduit and the chief mains.

GEO. LAMBERT, *M. Inst. C. E.*,
Executive Engineer, Hyderabad Canals.

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APPENDIX No. 1.

Register of Monthly Pumping Operations and consumption of Fuel.

Month.	A. River Lift. 1881-82.					A. River Lift. 1882-83.					B. Fort Lift. 1881-82.					B. Fort Lift. 1882-83.					C. Cantonment Lift. 1881-82.					C. Cantonment Lift. 1882-83.				
	Number of pumpings.	Time. Hours.	Time. Minutes.	Fuel.	Gallons.	Number of pumpings.	Time. Hours.	Time. Minutes.	Fuel.	Gallons.	Number of pumpings.	Time. Hours.	Time. Minutes.	Fuel.	Gallons.	Number of pumpings.	Time. Hours.	Time. Minutes.	Fuel.	Gallons.	Number of pumpings.	Time. Hours.	Time. Minutes.	Fuel.	Gallons.	Number of pumpings.	Time. Hours.	Time. Minutes.	Fuel.	Gallons.
April . .	5	45	50	48,020	5,888,800	8	71	25	78,090	8,937,600	4	19	50	17,214	1,624,980	11	64	50	58,597	5,254,300	24	179	25	34,942	2,865,200	17	120	10	30,438	1,924,550
May . .	8	65	25	61,486	8,937,600	9	75	25	87,460	10,054,800	13	62	40	52,812	5,193,725	13	85	50	78,707	6,989,257	18	174	25	41,744	2,652,340	18	151	...	36,863	2,342,000
June . .	8	63	15	53,330	8,937,600	10	79	50	74,250	11,172,000	14	66	50	56,689	5,442,100	13	89	55	84,498	7,314,225	17	151	25	38,460	2,433,340	17	153	55	37,290	2,350,900
July . .	7	52	50	43,605	7,778,400	7	54	40	44,230	7,820,400	13	61	25	52,195	5,077,400	12	73	10	66,290	5,963,700	19	155	25	37,870	2,397,400	18	128	50	32,885	2,067,100
August . .	6	45	5	36,140	6,703,200	7	53	20	34,920	7,820,400	12	49	35	41,911	4,111,200	11	64	30	58,347	5,256,700	18	124	55	31,733	2,007,400	17	112	35	29,101	1,802,300
September .	5	38	10	29,570	5,586,000	8	63	35	46,970	8,937,600	9	45	15	38,205	3,717,080	11	72	10	68,192	5,843,200	16	123	20	30,887	1,941,100	18	127	5	32,567	2,055,700
October .	6	53	15	42,790	6,526,800	8	66	5	54,480	8,727,600	9	51	15	44,669	4,198,600	11	75	10	71,692	6,088,600	18	123	20	31,487	1,988,800	17	114	5	29,555	1,843,900
November .	5	41	10	40,020	5,661,600	7	61	35	51,000	7,820,400	8	36	40	31,258	3,053,200	9	60	35	57,040	4,909,200	17	91	25	24,060	1,554,000	17	108	55	27,529	1,708,800
December .	5	44	...	47,750	5,585,800	7	65	26	52,750	7,820,400	9	37	45	32,734	3,159,700	11	70	35	66,206	5,706,300	14	75	25	20,189	1,293,500	18	100	35	26,768	1,689,200
January .	5	43	15	44,230	5,586,000	6	59	...	56,380	6,703,200	9	39	45	34,258	3,314,700	10	60	40	53,514	4,886,700	12	75	55	19,880	1,273,500	18	102	55	27,333	1,734,800
February .	4	35	45	34,050	4,468,800	6	54	25	53,160	6,703,200	8	37	55	31,904	3,166,025	8	49	5	43,752	3,997,400	11	74	35	19,047	1,205,200	16	86	40	23,025	1,475,500
March . .	6	51	40	54,720	6,703,200	7	72	55	68,160	7,820,400	9	53	15	46,791	4,339,400	11	67	45	87,300	5,504,000	18	107	5	28,244	1,792,900	18	118	35	30,742	1,923,200
Total .	70	...	...	535,711	78,263,800	90	...	...	701,850	100,338,000	117	...	...	480,640	46,398,110	131	...	...	794,135	67,718,582	202	...	...	359,543	23,404,680	209	...	...	364,096	22,917,950

GEO. LAMBERT, *M. Inst. C. E.*,
Executive Engineer, Hyderabad Canals.

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APPENDIX No. II.

Statement showing the Cost of Hyderabad Water-Works.

	Description.		A. Cost of Works common to City and Cantonment.	B. Cost of City proper.	C. Cost of special works for Cantonment.	Total.	Remarks
			R	R	R	R	
River Lift.		Masonry	1,503	12,024	...	13,527	
		Pipe-wall	119	948	...	1,067	
		Engine house building	697	5,575	...	6,272	
		Machinery	2,922	23,373	...	26,295	
	Aqueduct	Masonry, &c.	1,856	14,847	...	16,703	
		Fittings	35	280	...	315	
	Depositing Tank	Masonry work	4,024	32,188	...	36,212	
		Fittings	342	2,740	...	3,082	
	Conduit	Masonry work	46,137	28,372	...	74,509	
		Fittings	606	...	...	606	
	Road Tanks	Masonry, &c.	...	1,067	...	1,067	
		Drainage, Bridges, &c.	...	3,677	...	3,677	
	Shah-Kadum Tank		...	30,217	...	30,217	
Fort Lift.		Masonry, &c.	...	8,227	...	8,227	
		Machinery	...	35,906	...	35,906	
	Fort Tank	Masonry, &c.	...	20,000	...	20,000	
		Fittings	...	152	...	152	
	Piping	Earth and Masonry	...	9,973	...	9,973	
		Pipes	...	54,083	...	54,083	
		Service Fittings	...	10,784	...	10,784	
	Jail Tank		...	918	...	918	
	Store and Shops		...	573	...	573	
	Bathing Tanks		...	5,640	...	5,640	
	Municipal Hydrant		...	20	...	20	
Cantonment Proper.		Masonry	...	...	20,612	20,612	
		Iron pipes, complete	...	...	27,563	27,563	
		Fittings, complete	...	...	2,693	2,693	
		Iron Tank	...	...	1,915	1,915	
		Machinery, complete	...	...	4,880	4,880	
		16 Street Hydrants	...	...	320	320	
	Total of each Work		58,241	3,01,584	57,983	4,17,808	

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Executive Engineer, Hyderabad Canals.

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APPENDIX No. III.

Working Expenses of the Hyderabad Water Works from 1st April 1881 to 31st March 1883.

	Description.	From 1st April 1881 to 31st March 1882.		From 1st April 1882 to 31st March 1883.		Remarks.
		Number or Quantity.	Amount.	Number or Quantity.	Amount.	
			℟ a. p.		℟ a. p.	
River Lift.	Working Establishment	12 months.	1,243 5 11	12 months.	1,152 0 0	
	Wear and tear of Machinery or 10 per cent. on ℟ 26,295-1-0 per annum	12 do.	2,629 8 0	12 do.	2,629 8 0	
	Deterioration of buildings, &c., or 2 per cent. on cost ℟ 1,57,576-5-6 of works common to both City and Cantonment	12 do.	3,151 8 5	12 do.	3,151 8 5	
	Salary to Mechanical Engineer	12 do.	4,200 0 0	12 do.	4,200 0 0	
	Fuel @ ℟ 18 per 100 maunds	6,696·38	1,205 5 6	8,773 12	1,579 2 3	
	Oil, tallow, spun yarn, &c., @ ℟ 3-13-1 per pumping	70 number.	267 3 10	90 number.	343 9 6	
	Red and white lead @ ℟ 4-4-0 per mensem	12 months.	51 0 0	12 months.	51 0 0	
	Total	...	12,747 15 8	...	13,106 12 2	A.
Fort Lift.	Working Establishment	12 months.	1,147 0 0	12 months.	1,152 0 0	
	Wear and tear of Machinery or 10 per cent. on ℟ 35,906	12 do.	3,590 9 7	12 do.	3,590 9 7	
	Deterioration of buildings, &c., or 2 per cent. on cost ℟ 1,92,244-13-5	12 do.	3,844 14 1	12 do.	3,844 14 1	
	Fuel @ ℟ 20 per 100 maunds	6,008	1,201 9 7	9,926·68	1,785 5 5	
	Oil, tallow, spun yarn, &c., @ ℟ 3-13-1 per pumping	117 number.	446 10 9	131 number.	500 1 11	
	Red and white lead @ ℟ 4-4-0 per mensem	12 months.	51 0 0	12 months.	51 0 0	
	Total	...	10,281 12 0	...	10,923 15 0	B.
Cantonment Lift.	Working Establishment	12 months.	732 0 0	12 months.	732 0 0	
	Wear and tear of Machinery or 10 per cent. on ℟ 4,480	12 do.	448 0 0	12 do.	448 0 0	
	Deterioration of buildings, &c., or 2 per cent. on cost ℟ 66,093-9-3	12 do.	1,321 13 11	12 do.	1,321 13 11	
	Fuel @ ℟ 20 per 100 maunds	4,481·53	806 10 9	4,551·2	819 2 10	
	Oil, tallow, spun yarn, &c., @ ℟ 1-8-0 per pumping	202 number.	303 0 0	209 number.	313 8 0	
	Red and white lead @ ℟ 4-4-0 per mensem	12 months.	51 0 0	12 months.	51 0 0	
	Total	...	3,662 8 8	...	3,685 8 9	C.

GEO. LAMBERT, *M. Inst. C.E.*,
Executive Engineer, Hyderabad Canals.

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MEMOIR OF THE KARACHI WATER-WORKS.

[Commenced 18th February 1880—Opened 21st April 1883—Finally completed as originally designed, November 1884.]

Historical.

From the Conquest of Sind by Sir Charles Napier till the commencement of the works described in the present paper, the necessity for an improved water supply for Karachi had been admitted on all sides, by all classes of people connected with the city, and various schemes had been brought forward, from time to time, for effecting the desired object.

Amongst the schemes proposed were the following:—

To construct a bund across the Hubb river, which, with the exception of the Indus, is the only perennial stream in Sind.

To construct a boat canal from the Indus to Karachi; and it was also proposed that a dam should be constructed across the Damlote valley, along which flows, in time of rain, the river of that name, a tributary of the Malir.

The consensus of professional opinion pointed, however, to a scheme, having the river Malir as the source of supply, as being in every way more feasible than any of the others; but it was not till 1868, when Colonel now (Lieutenant-General) Merriman carried out an important experiment to test the capabilities of the supply of that underground river, that the public mind was satisfied on the subject. The experiment consisted in ascertaining, by means of pumping at what level 1,200 gallons of water per minute could be obtained, this being the quantity necessary to supply Karachi with 22 gallons per head per diem for a population of 80,000 inhabitants. The experiment proved beyond a doubt that the requisite quantity of water could be obtained at no great depth. This point being satisfactorily settled, Colonel Merriman next submitted a scheme for bringing the water into Karachi from wells to be sunk on the banks of the river. The water was to be brought in cast-iron pipes, and the cost of the work was estimated at Rs. 15,25,000. Unfortunately, before the arrangements for commencing the work could be completed, the price of iron in England rose to such an extent that the execution of the project was indefinitely deferred by the Municipality, the money at their command was not sufficient to meet the increased cost, and the members could not be got to face the responsibility of raising a loan.

In 1873, on the writer being appointed Engineer and Secretary to the Karachi Municipality, he took up the question of the water-supply, and brought the matter prominently before the Municipality. He proposed that, instead of cast-iron pipes, which were still very dear, advantage should be taken of the excellent stone found in the neighbourhood, and that the water should be brought to Karachi from the wells to the Malir in a masonry conduit, built underground.

Plans were prepared by the writer, which in due course received the approval of the Municipality, but, unhappily, the estimated cost of the works, *viz.*, ₹12,00,000, was still considered by them beyond their means. Under these circumstances, the execution of the scheme would again have been indefinitely postponed, had not the writer proposed to curtail the distributing pipes, so as to bring the amount of the estimate down to ₹8,50,000, the sum which the Municipality were willing at first to spend. Government granted their sanction to the scheme as reduced, and after many and great delays, attributable to various causes, the foundation stone of the distributing reservoir was laid on the 18th February 1880, by Sir Richard Temple, G.C.S.I., then Governor of Bombay.

It may be here mentioned that the new works, according to the reduced plan, had no sooner been completed, and the water brought into Karachi, than such was the appreciation of the public, that a demand was raised for the completion of the scheme as originally designed. Application was accordingly made to Government, on 28th June 1883, for permission to raise a loan for the execution of the remainder of the works; the loan was sanctioned, and the works are now complete.

Descriptive, General.

The Malir river, from which the water for the supply of Karachi is obtained, has its rise in the mountainous district between Karachi and Sehwan, in about latitude 25° 20′N., longitude 67° 38′E. It is dry for the greater part of the year, but, as has been already shown, water is readily obtained in the sandy bed by digging down a few feet below the surface.

The site selected for the wells was not the one at which General Merriman's experiment was carried out, but one 2 miles further up the river. This change of route secured a greater fall for the conduit, and permitted its being constructed underground for the whole of its length, which was a great desideratum.

The Malir river, at the site of the wells, is about 700 yards wide, and, when flooded, discharges a vast body of water. The country drained by it is about 600 square miles in extent,

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and but sparsely populated. The surface of the country between the Malir and Karachi is generally even, the height above sea level at the highest point on the line of conduit being about 176 feet; it is composed of alternations of gravel and sand and a pale alluvium loam and gravel. In the vicinity of the river the soil is a light loam, containing a large proportion of micaceous particles. The geological formation of this tract, as seen from the section exposed by the excavation for the work, differs in no material respect from that prevailing in Lower Sind, and is identical with what has been termed the *gaj* or *miocene* group, intermingled with the *munchars* or *pliocene*.

The general section in descending order (as shown especially in the excavation for the distributing reservoir at Karachi) is—

1. Conglomerate.
2. Clay and sand-stone.
3. Upper bone bed.
4. Sand-stones.
5. A pale yellow arenacious lime-stone, more or less pure, followed in some places by a thin stratum of nummulitic lime-stone.

The sand-stones and lime-stones found at intervals in the trenches between Karachi and Malir form thin beds, nowhere exceeding 15 feet in thickness. The conglomerate was of an exceedingly hard description, and gave much trouble to excavate.

Description of work.

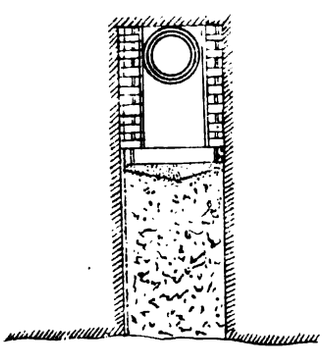
The works now to be described consist of two wells sunk on the banks of the Malir river, connected with a distributing reservoir near Karachi, by means of a masonry conduit, about 18 miles in length. The water of the reservoir is deliveredin town and camp through cast-iron pipes, and public services are also erected at various points.

The wells.

The wells are two in number, and are forty feet in diameter each. They are sunk 400 feet apart, and 1,000 feet from the banks of the river, as the latter are liable to be eroded in time of flood. They were excavated to their full depth (36 feet) without the aid of pumps of any kind. The manner in which this was accomplished will be readily understood by a reference to the section, Drawing No. 1, which accompanies this paper. About three miles from the Malir river the line of conduit crosses the Thudda river; and as the bed of this river at the point of crossing was at a lower level than the bottom of the wells, the excavation of the trench for the conduit was commenced from this point, and all the water found in both the conduit trench and the wells drained into the Thudda. Had it been impossible to drain off the water of the wells in this manner, the additional cost of pumping would have been enormous, as, for many months, 2 millions of gallons of water were discharged daily through the trench.

The excavation having been completed, the steining of the wells was next commenced. This consisted of ashlar blocks, 3 feet long × 1·6 × 1·0, laid header and stretcher alternately. The beds and joints of the blocks were purposely left rough, so as to admit the water freely. The wall is 3 feet thick and set dry; it is carried to a height of 23 feet above ground level, and finished with an ashlar cornice. In the centre of each well a cast-iron valve shaft, 4 feet in diameter, has been erected (Drawing No. 3); with this valve shaft is connected the 24-inch pipe, which carries the water to the junction tank where the masonry conduit commences.

The junction tank (Drawing No. 4) is built near the point at which water was found in the conduit trench, a distance of 1,666 lineal yards from the Malir wells; and in order to utilize this excavation as a gathering gallery, the pipe between the junction tank and the wells was encased in rough dry rubble walls, thus :—



All the pipes here referred to had turned and bored joints, and consequently were easily laid in water.

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Kasum Ka Gala

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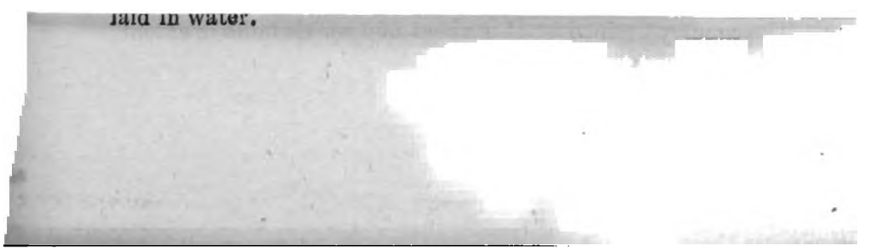
laid in water.



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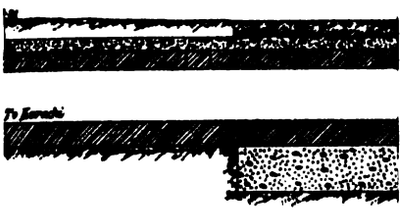
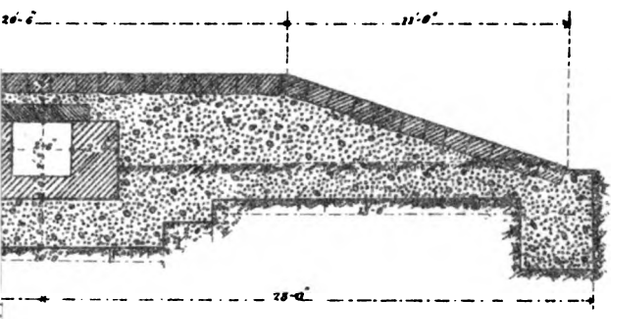
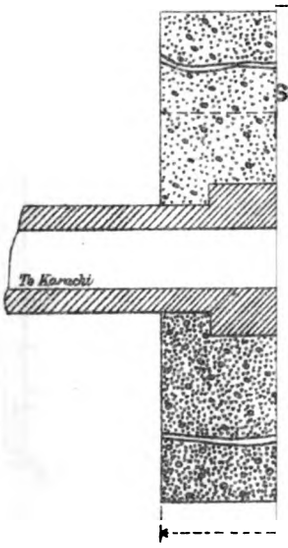
T. 70 — 2.

Drawing No 2







SECTION ON A. B.

Strachan, M.I.C.E.,
Principal Engineer and Secretary.

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DRAWING Nº 3.

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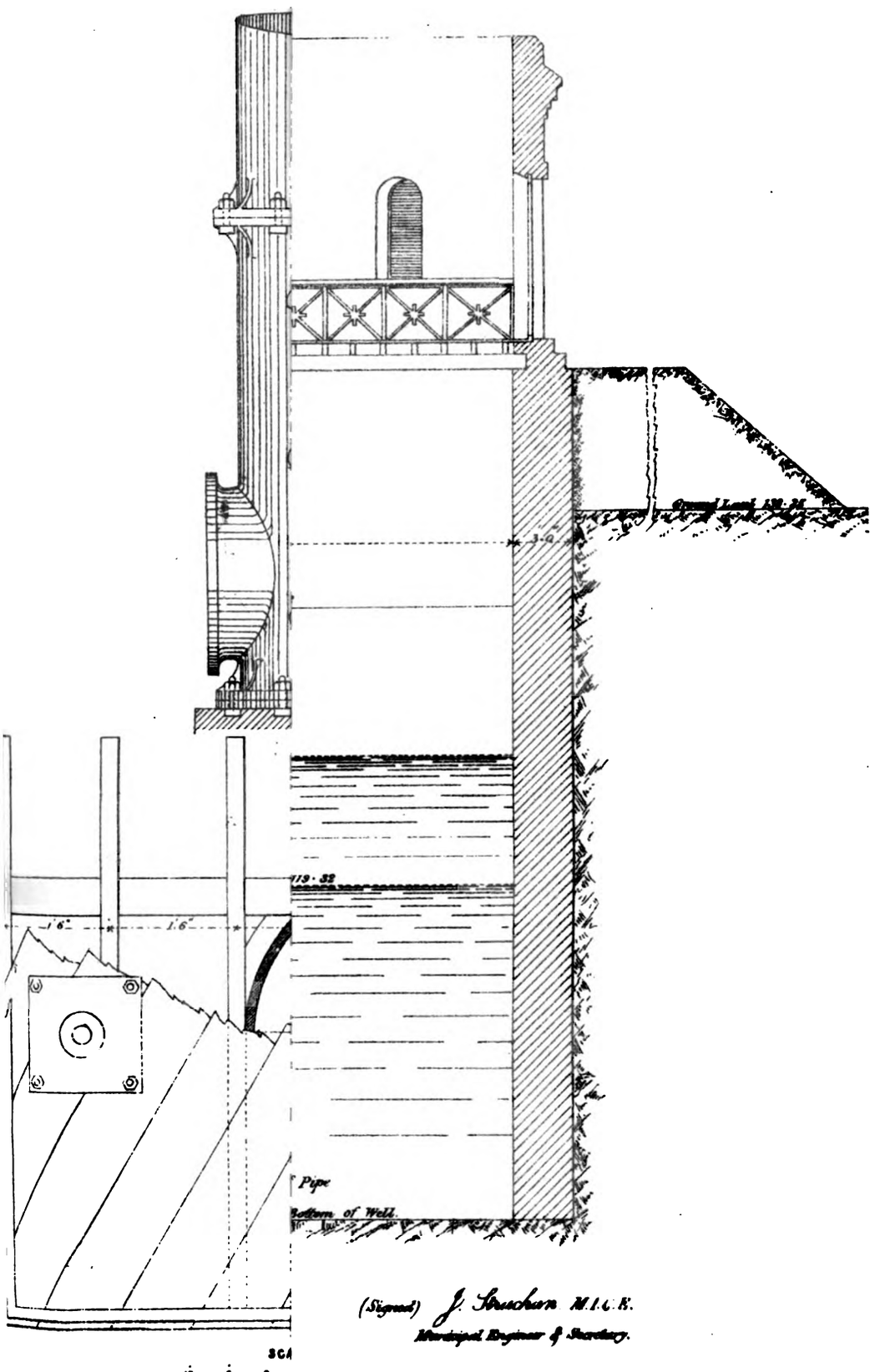

(Signed) J. Strachan M.I.C.E.
Municipal Engineer of Secretary.

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OF INDIA OFFICE, CALCUTTA, SEPTEMBER 1888.

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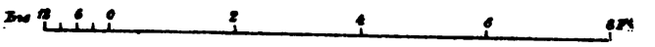
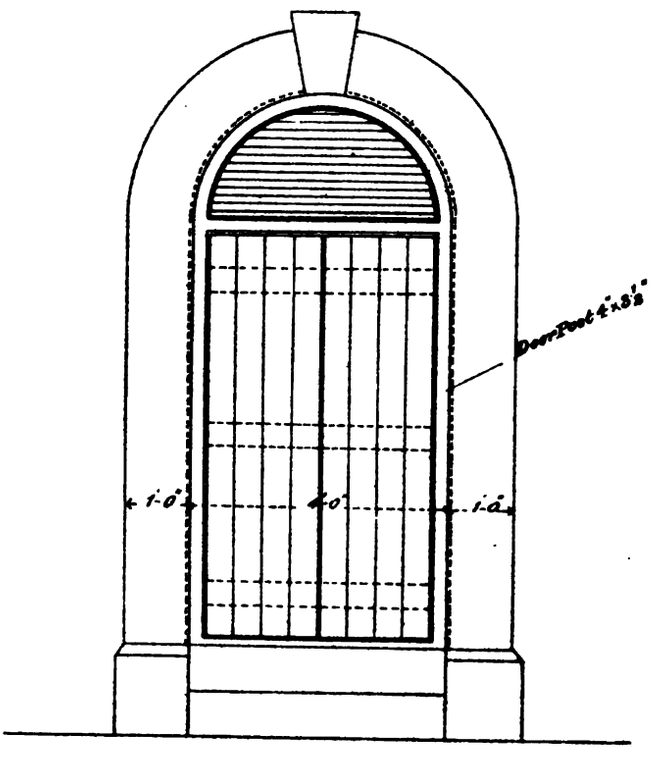
DRAWING No. 4.

DETAIL OF DOOR.

Scale of Feet.





FRONT ELEVATION

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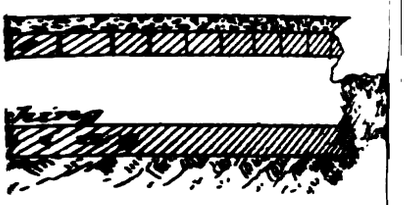
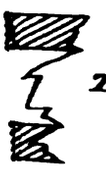
Drawing No 6.





To Karachi

J. Strachan. M.I.C.E.
Canal Engineer & Secretary.

A.S. WEBB SURVEY OF INDIA OFFICE, CALCUTTA.

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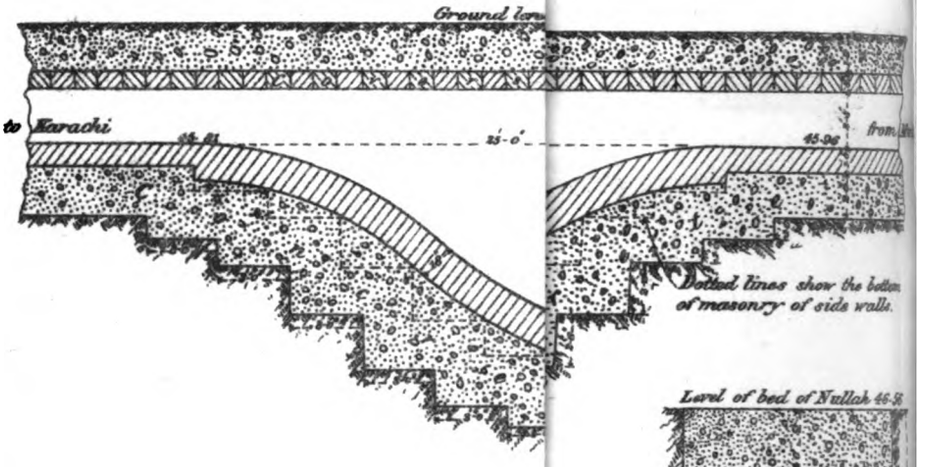
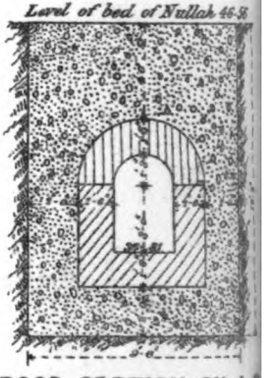
F. 71

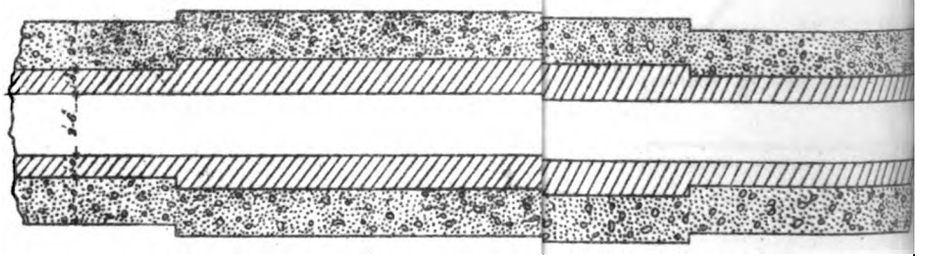
DRAWING Nº 7.

N.B. – Underside of Covers to be lined
Cement 50 feet from ventilating





CROSS SECTION ON A.B



(Signed) J. Strachan, M.I.C.E.
Municipal Engineer and Surv

AT THE SURVEY OF INDIA OFFICES, CALCUTTA, MARCH

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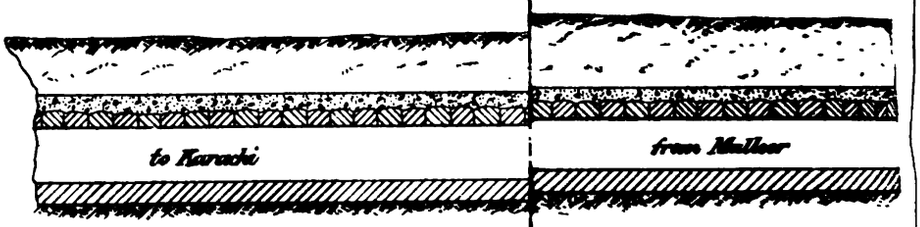
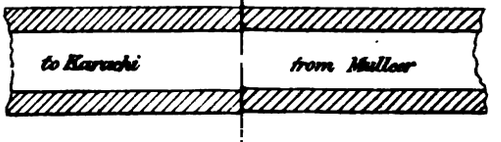
DRAWING Nº 8.





J. Strachan, M. I. C. E.,
Municipal Engineer and Secretary

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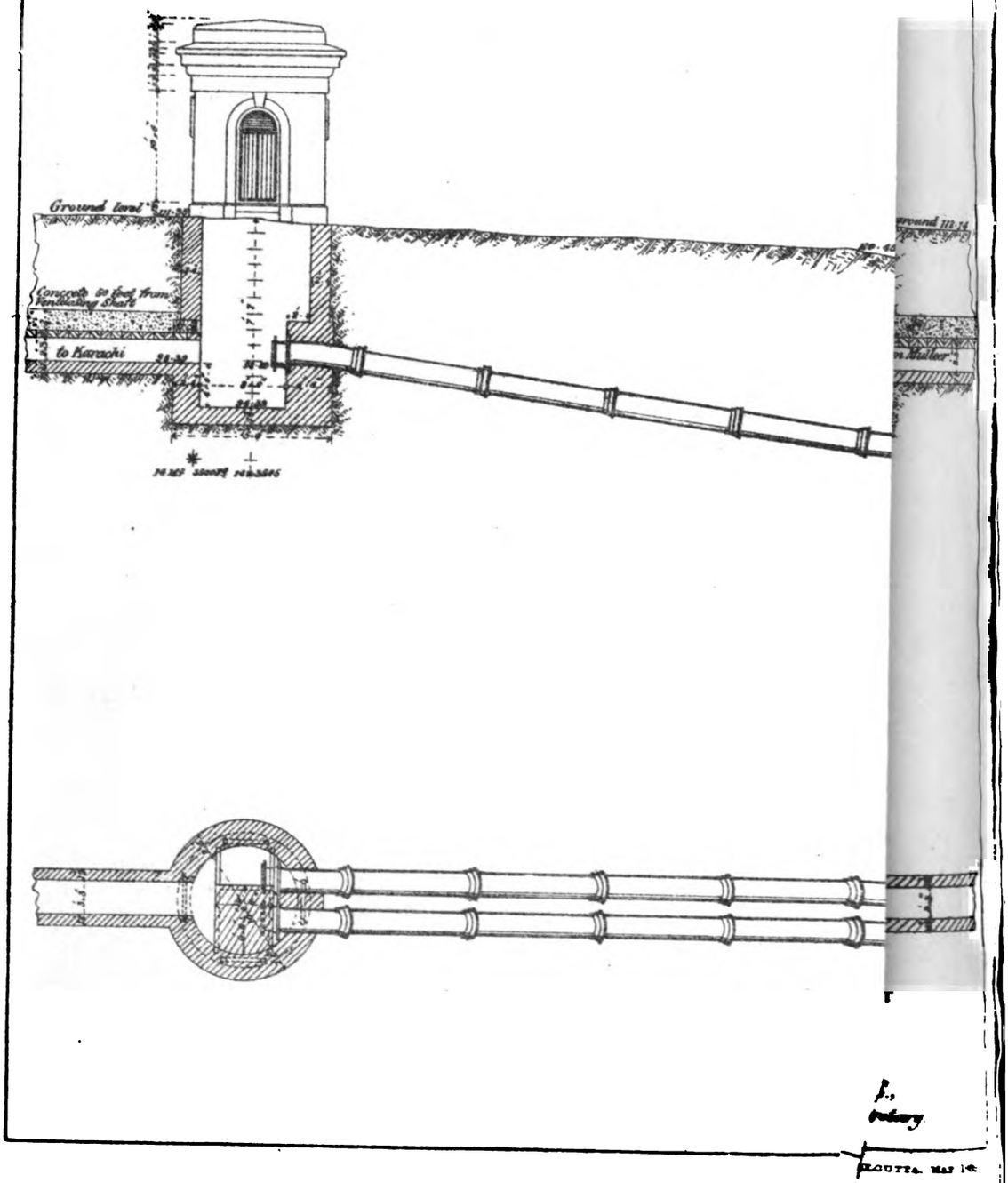
D.



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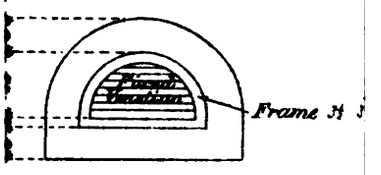
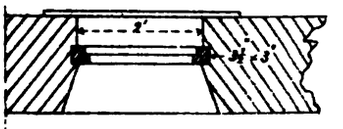
RAWING Nº II.

TAIL OF WINDOW

Scale of Feet

ELEVATION





PLAN OF WINDOW

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I. 11

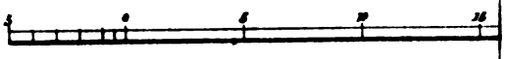
DRAWING Nº 13.

KARACHI WATER WO

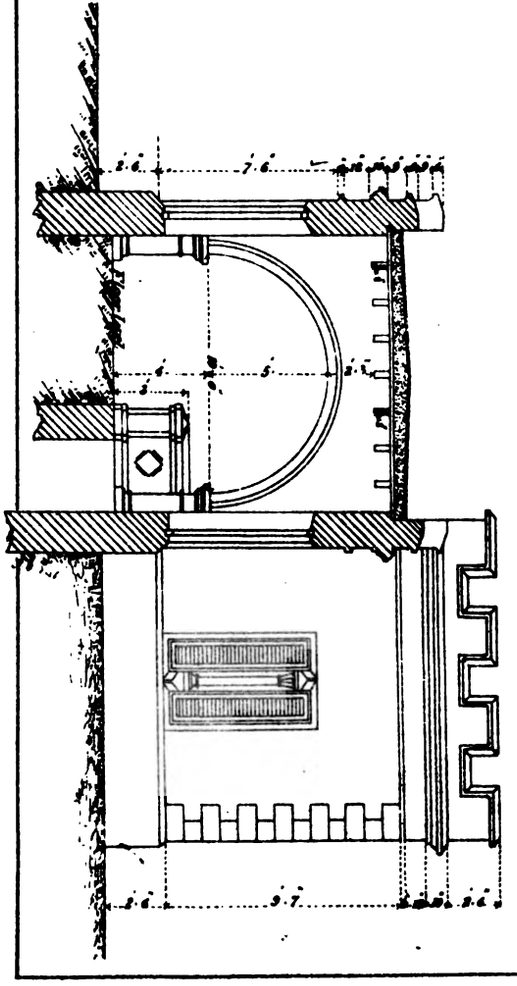
INLET WELL

AT JUNCTION WITH RES

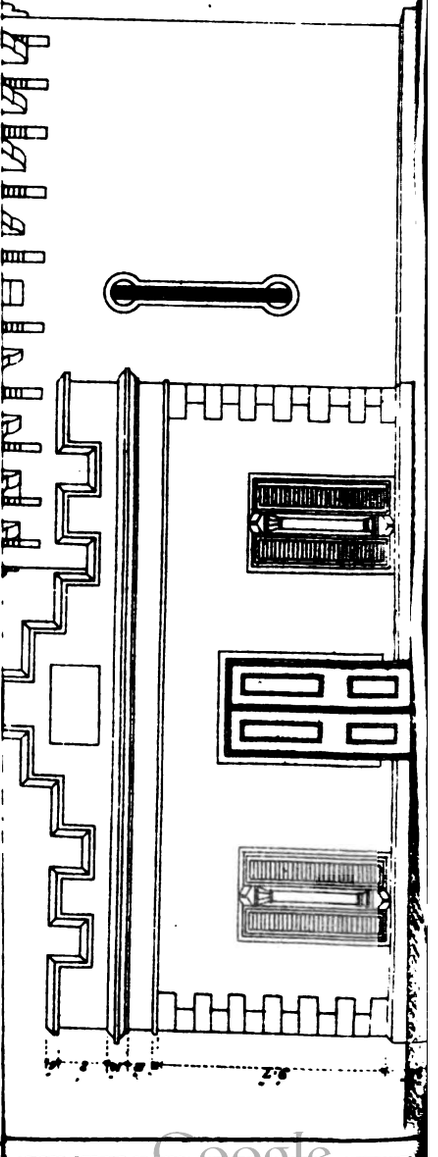
Scale of Feet



(Signed) J. Strac
Municipal Eng



CROSS SECTION ON A.B.



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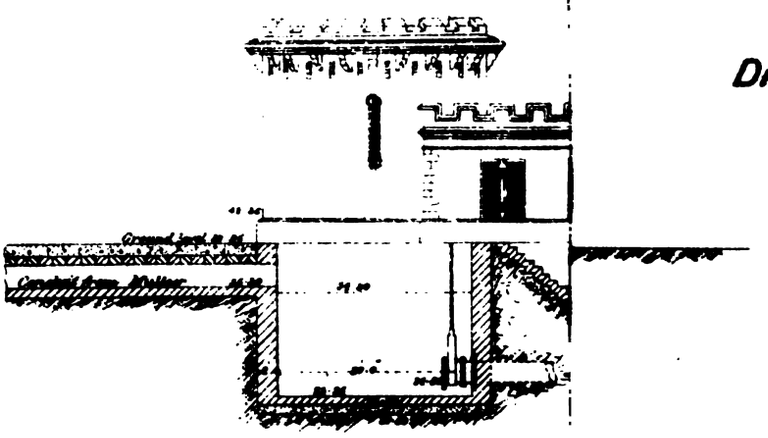
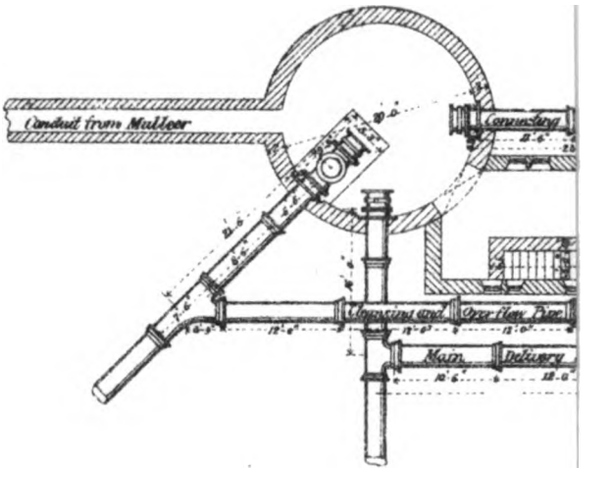
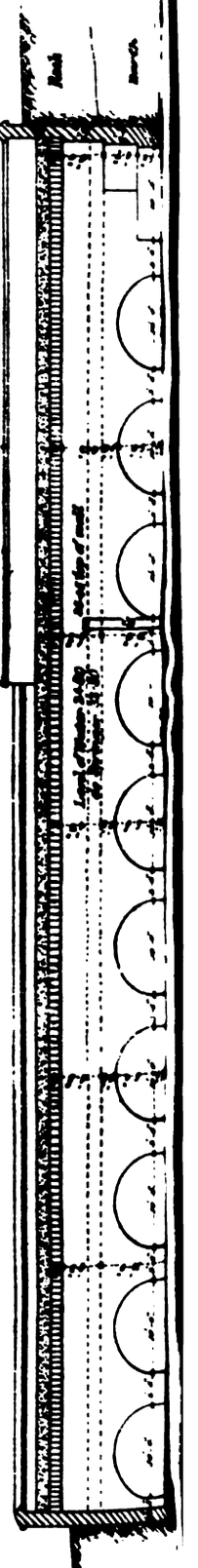
DRAWING Nº I



INLET WELL



CROSS SECTION ON A. B.



...achan, M.I.C.E.,
...l Engineer and Secretary.
...VISIONS, CALCUTTA, SEPTEMBER 1869.

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average level of the ground-floor of the houses in the native town.

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...achan, M. I. C. E.,
...l Engineer and Secretary.
...VISORS, CALCUTTA, SEPTEMBER 1868.

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Conduit.

The conduit, including the various syphons, is in length 17 miles 36 chains, and is in section as per Drawing No. 5, and is built of common rubble masonry set in lime mortar. The walls are only 12 inches thick, but it was specified that all stones used in the work should go right through the wall; a coating of Portland cement plaster, half an inch in thickness, was laid on the face of walls and invert. Over the covers, which are 8 inches thick, is laid a coating of concrete 6 inches, thick. Where the culvert is in a shallow cutting, and where the rain water was likely to soak through the earth above the concrete, the thickness of the latter was increased.

Syphons.

Drawings Nos. 6, 7, 8, 9, and 10 show the syphons which were constructed to carry the water of the conduit under the nullahs which had to be avoided.

The masonry of the walls is common rubble; that of the arch is block-in-course.

The concrete used was mixed in the following proportions, *viz.*, 5 parts of broken stone, 2 parts of river sand, and one part of lime. The whole of the internal walls of stone syphons including the soffit of the arch, are rendered in cement in a similar manner to the walls of the conduit.

Ventilating Shafts.

Ventilating shafts (Drawing No. 11) are provided at intervals of one mile where the conduit is not in deep cutting, and of half a mile at other places. Foot irons are provided in each shaft, to enable an inspection of the conduit to be made at any time.

Water in Conduit.

In excavating for the conduit, except when the Malir stratum was reached, water was only found at one point along the line, and as it was brackish, it was absolutely necessary to prevent its admission to the conduit. To effect this a layer of concrete was laid on the bottom of the excavation, and the side walls were carried up to a height of 6 feet; while plastering the walls, the water was observed to break through in several places at the foot, carrying with it small portions of the unset plaster, and all attempts to stop the leaks proved unsuccessful. Had the cutting been opened out below this point, it is believed that the water would have been drained off, but, unfortunately, there was no opening at the lower end, and as it was important to push on with this part of the work, as the sides of the excavation, where there was shale, showed signs of falling in, it was resolved to insert through the wall, at intervals, short pieces of iron piping; by this mean the water was allowed free ingress to the conduit, and the cement plaster set hard without any further difficulty. As soon as the plaster was properly set, the pipes were plugged up.

Branch for Irrigation of land.

At about 2 miles from the reservoir, where there was arable land available, and where the level suited, a well was built (Drawing No. 12) for the purpose of irrigating the adjoining land. In this well are two valves, one on the line of conduit, and the other on the pipe leading to the irrigation channel. They are worked by bevelled pinions on the same spindle, and so arranged that when one is open the other is shut.

Inlet well.

The inlet well (Drawing No. 13) into which the water, carried by the conduit, is discharged, is built adjoining the reservoir, and acts as a second chamber to it. It is 20 feet in diameter, lined with ashlar, 2 feet in thickness, set in Portland cement mortar. The walls are carried up 24 feet above ground, and finished with an ashlar battlemented cornice.

Reservoir.

The distributing reservoir (Drawing No. 14) is 200 feet long by 150 feet wide. The top water surface is 10 feet 9 inches above the floor. The total quantity the resevoir will contain is thus a little short of 2,000,000 gallons. The reservoir is built in excavation; the foundation, which is laid on a bed of clay shale, consists of a layer of concrete, 12 inches in thickness over the whole area of the excavation, with a course of large flat-bedded rubble, 8 inches in thickness, laid above; on this the walls and piers are built; they are 18 inches in thickness, of coursed rubble, and support segmental arches of block-in-course masonry, 15 inches in thickness. The main arches have a span of 12 feet ¾ inch, and a rise of 4·3 inches. The piers have also arched openings. A wall of masonry, running nearly the whole length of the reservoir, divides the inlet pipe from the main delivery, and thus a complete circulation of the water in the reservoir is maintained.

The whole of the internal walls of the reservoir up to 3 inches above top water level, are rendered in cement plaster one inch thick. The cement was composed of 3 parts of sand to one part of Portland cement. Two cast-iron ventilators, 9″ diameter, are fixed into each compartment of the reservoir. The spandrils are filled with rubble masonry, and the top of the arches covered with concrete to the depth of one foot; above the concrete 1′6″ of soil has been spread, and a garden formed.

Distributing Pipes.

The levels of the delivery pipes in the reservoir and inlet well correspond, and are 10·0 feet below the top water level of the reservoir. The latter is 62·35 feet above the mean sea level, and 55 feet above the average level of the ground-floor of the houses in the native town.

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The main delivery pipes are of cast-iron, 24 inches diameter and ¾ of an inch in thickness of metal, and have two branches, one from the inlet well, and the other from the reservoir. These pipes are fitted at the ends in the well and reservoir, respectively, with 24-inch sluice valves, so that water can be supplied to the town direct from either, as occasion may require. A cast-iron pipe, 24 inches diameter, connects the inlet well and the reservoir; it is controlled by a 24-inch valve on the end of the pipe in the well; the end of pipe in reservoir is bell-mouthed. The arrangements for cleansing both the inlet well and the reservoir are similarly designed.

The cleansing pipe, which communicates, at some distance from the reservoir, with a built drain, is laid two feet below the level of the main delivery pipe, and, like it, has one branch from the well and one from the reservoir, ending in each case with a sluice valve of the same description as those on the delivery pipes. Immediately behind the valves on the cleansing pipes, in both the inlet well and the reservoir, flanges have been cast, forming seats for the overflow pipes, which are also 24 inches in diameter.

All the valves are faced with gun-metal, and are worked from the valve-house, by wheels fitted on the end of wrought-iron rods, working in pillars firmly fixed to the floor.

The distributing pipes are all of cast-iron; 80 per cent. have turned and bored joints, and 20 per cent. lead joints. The hydrants are of the ordinary pattern, of the strongest description made (Drawing No. 15), and are placed 200 feet apart in the principal thoroughfares to facilitate street watering; in other streets they are 400 feet apart.

Drawing No. 16 shows a bhisti service, at which the bullock puckhauls are filled. The total number of these services is 40.

Drawing No. 17 shows the public street services, of which 28 are erected at various parts of the town.

Stand-posts of the ordinary pattern (Drawing No. 18) have also been erected at different places.

A five-inch pipe has been laid down for a special supply of water to the Sind, Punjab and Delhi Railway, and a 6-inch pipe has been laid to Keamari, a distance of over five miles from civil lines, for supplying the shipping and the engine-house at Merewether Pier. The pipes to Keamari had to be taken under a screw pile bridge, consisting of 30 spans each of 40 feet. The pipes were suspended under the cross girders of the bridge, and an expansion joint, shown in Drawing No. 19, was provided, which is found to act admirably.

Lengths, weights, and thickness of the metal of the various pipes used.

The following is a statement of the lengths, weights, and thickness of metal of the various mains used in distributing the water in town and camp:—

Diameter in inches.	Length in yards.	Weight in tons.	Thickness of metal in inches.
24	68	19	¾
21	2,356	530	11/16
18	2,308	424	11/16
15	528	77	⅝
12	2,646	270	½
9	3,336	237	½
7	1,266	62	7/16
6	9,675	394	7/16
5	10,725	343	⅜
4	8,838	209	⅜
3	12,375	190	5/16
2½	1,860	24	5/16

Stone used on the works.

The stone used on the works was that commonly quarried in the neighbourhood, and is an arenacious lime-stone, composed as follows:—

Clay	5·60
Free sand	9·30
Oxide of iron	2·00
Carbonate of lime	80·00
Carbonate of magnesia	1·90
Moisture and loss	1·20
	100·00

Total cost of the work.

The total cost of the scheme as it is now completed amounts to nearly ₹11,50,000. The cost of supervision amounted to less than 4 per cent. of the total cost of the work. The maximum daily supply possible is 2,500,000 gallons, or 25 gallons per head per diem for a population of 100,000. The cost of a permanent supply of 25 gallons per diem is thus ₹11-8.

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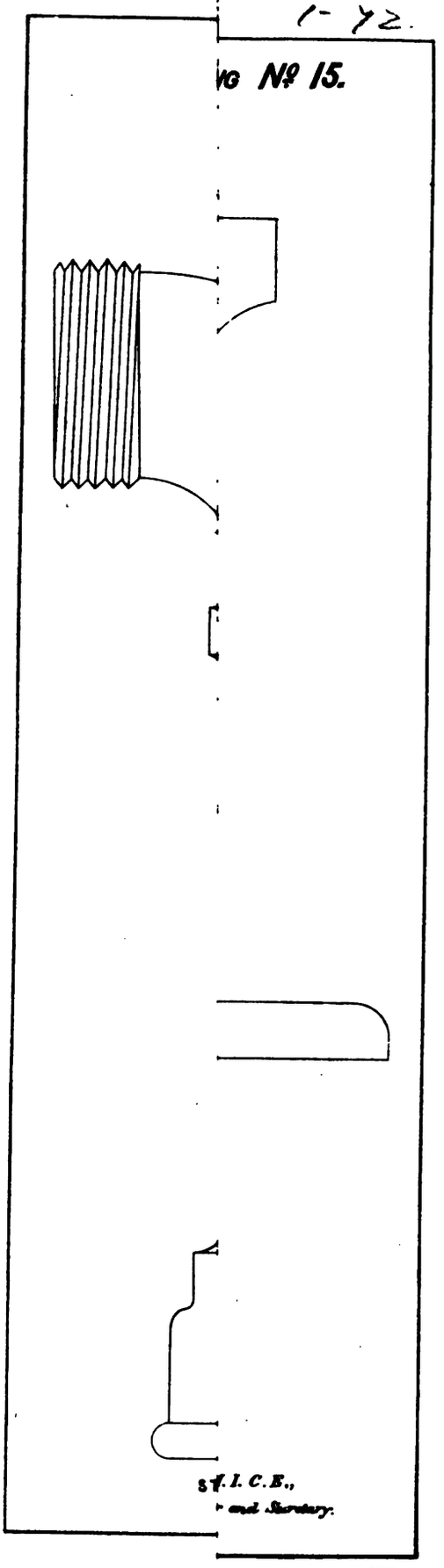
VG № 15.



S. I. C. E.,
and Secretary.

CALCUTTA, SEPTEMBER 1869.

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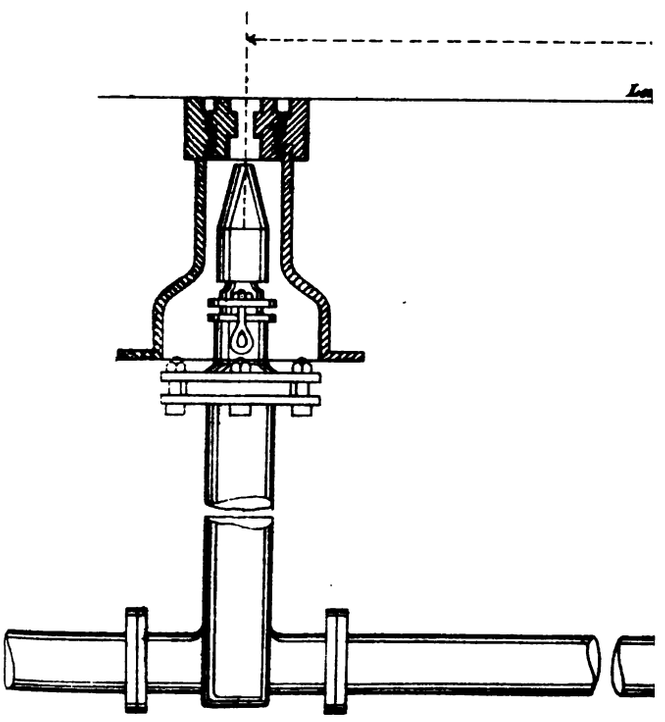
KARACHI WATER

DRAWING OF STAN

Scale of Feet

Inches 12 11 10 9 8 7 6 5 4 3 2 1 0



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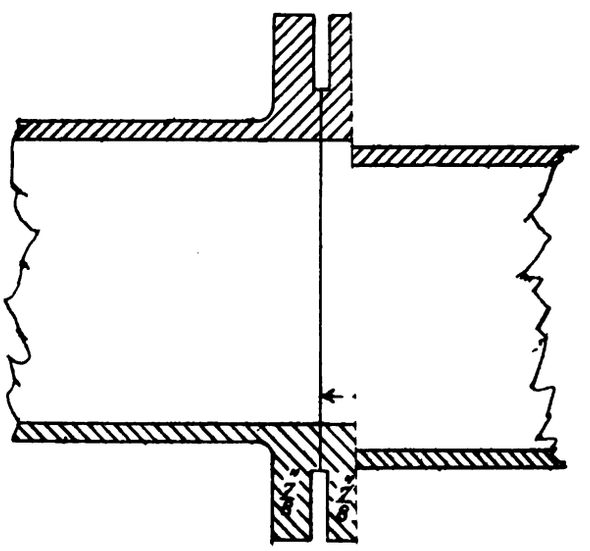
DRAWING Nº 19.



J. Strachan, M.I.C.E.
Municipal Engineer & Secretary.

LITHOGRAPHED AT THE SURVEY OF INDIA OFFICES, CALCUTTA, JANUARY 1869.

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The total cost of the reservoir was ₹67,000, and as it is capable of containing 2,000,000 gallons of water, the cost per 1,000 gallons of water stored is ₹33·50, a cost which compares favourably with other works of a like nature.

Flow of water in the conduit.

From observations carefully taken along the line of conduit, it was found that the velocities due to the different areas of water channel, and to the different grades are as under :—

No.	Sectional area of water in conduit.	Gradient of conduit per mile.	Velocity in feet per minute.	Actual discharge in cubic feet per minute.
1	1·10 feet.	3·91	88	96·80
2	0·75 feet.	9·0	128	96·00
3	1·46 feet.	2·00	66	96·52

Thus, corresponding with the formula $V=\sqrt{\frac{K.D.}{s}}$, taking the value of the constant K. at 8,800.

The following Table A. shows the analysis of the water supplied to Karachi and the Troops in Garrison prior to the opening of the Karachi Water Works :—

TABLE A.

Dates of Collection.	Source.	Grains per Gallon.						Parts per million.		Remarks.
		Total solids.	Chlorine.	Sulphuric Acid.	Lime.	Magnesia.	Permanent hardness.	Free Ammonia.	Albumenoid Ammonia.	
1st October 1875 .	Filter Tank, Napier Barracks . .	49·91	16·10	...	...	...	...	·26	·18	
5th November 1875.	Wells in front of R. A. Barracks .	139·30	54·37	15·77	6·09	26·04	...	·02	·18	

The following Table B shows the analysis of water taken from the wells on the banks of the Malir river, from which the city of Karachi is now supplied with water :—

TABLE B.

Date of Collection.	Source.	Grains per gallon.						Parts per million.		Remarks.
		Total solids.	Chlorine.	Sulphuric Acid.	Lime.	Magnesia.	Permanent hardness.	Free Ammonia.	Albumenoid Ammonia.	
11th October 1875	Malir river wells.	24·36	4·06	2·40	3·45	2·32	5·20	·04	·08	The water was collected at a depth of 18 feet below the surface of the ground, or 10 feet below the bed of the river.

OPENING OF THE WORKS.

The works which had been for a week or two previously supplying water to the Camp and Town of Karachi, were formally opened to the public on the 21st April 1883. His Excellency Sir James Fergusson, K.C.M.G., C.I.E., Governor of Bombay, was invited to preside at the ceremony, but unfortunately his other duties prevented him from visiting Sind on that occasion. Mr. Birdwood, Judicial Commissioner in Sind, kindly undertook the duties on behalf of Mr. Erskine, Commissioner in Sind, who was prevented from attending owing to family bereavement. The day was observed as a holiday, and the utmost enthusiasm prevailed amongst all classes.

FINANCIAL RESULTS.

The rate charged for private supplies are as under, *viz.* :—

For water supplied through	½"	connection,	per mensem,	₹ 1.
Do.	do.	¾"	do.	do.	₹ 2-8.
Do.	do.	1"	do.	do.	₹. 5.

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Water supplied through pipes of larger diameters than the above is charged for by meter at the following rates :—

Through pipes	1¼"	diameter,	10 annas	per	1,000 gallons.
Do.	1½"	do.	9	do.	do.
Do.	2"	do.	8	do.	do.
Do.	3"	do.	7	do.	do.
Do.	over 3"	do.	6	do.	do.

Although the works have been completed for only a very short time, there have been already 533 private connections made with the mains, yielding an annual income of ₹11,784; the number of these connections is daily increasing.

The sum received from the Railway Company for water supplied amounts to ₹6,000 per annum, and a further sum of ₹6,132 per annum is received from sales of water to the shipping at Keamari, and the Native Jetty, and from supplies to steam engines and large establishments, making a present total income derived from the water-works of ₹23,916. The military authorities have not yet availed themselves of the advantages of a good water-supply to the extent they might have done; but if the offer of the Municipality is accepted they will be allowed an unrestricted supply for an annual payment of ₹10,000.

A water-rate has not as yet been imposed on the general public, but the advisability of doing so is being debated by some of the Municipal Commissioners, and will no doubt be carried out before long. If a tax at the rate of 3 per cent. per annum were imposed on the assessed value of the houses in Karachi which at present pay house-tax, the amount would come to ₹18,000, and thus a total of ₹51,916 would accrue. Of course this income could be very materially increased were the Commissioners so inclined. The rates for private connections might be raised 50 per cent. without the slightest remonstrance.

As the water flows by gravity from the wells to the distributing reservoir, there is no expense for pumping, and little or nothing required for maintenance and repairs. The following is the establishment retained specially for the maintenance and repairs of the water-works for the present :—

	₹	a.	p.
2 Mistries	125	0	0
1 Clerk	30	0	0
1 Peon	10	0	0
4 Line-guards	40	0	0
3 Valve-men	30	0	0
2 Turncocks	20	0	0
TOTAL PER MONTH	255	0	0
			12
TOTAL PER ANNUM	₹3,060	0	0

Deducting this sum from ₹51,916, it is evident that the income the Municipality expect to derive from the water-works is over 4 per cent. on the original outlay, an income which, as before remarked, might, without difficulty, be very materially increased.

J. STRACHAN, *M. I. C. E.*,
Engineer and Secretary, Karáchi Municipality.

SPECIFICATION OF THE VARIOUS WORKS CONNECTED WITH THE SCHEME FOR SUPPLYING KARACHI WITH WATER FROM THE MALIR RIVER.

1.—WELLS AT THE MALIR.

Number of wells. These wells are four in number, and will be sunk at the sites pointed out by the Executive Engineer to the Municipality.

Dimensions of the wells. The depths to which the wells will be sunk will be finally determined while the work is in progress; at present it is presumed they will vary from 35 to 40 feet deep. The inside diameter of each well, when finished, will be (40) forty feet. The excavation required to be taken out will be (52) fifty-two feet diameter, and no more will be paid for. The contractor will have to satisfy himself as to the quantity of water he will have to contend against, and frame his estimate accordingly, including in his rates the cost of all pumping machinery and fuel, shoring props, and all materials and labour of whatever description requsite to complete the work.

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The steining of the wells will be of concrete blocks, and will be 3 feet in thickness; the blocks to be set with dry beds and joints, to be perforated as may be directed, so as to admit the water freely. Each course must be laid with header and stretcher alternately; the headers to go right through the wall, and the stretchers to have breadth of bed equal to half the thickness of the wall.

Steining.

The stretchers must be close together in their back joints; no voids or packing of any description will be allowed.

All the blocks must be moulded to the curve of the well, and all the joints must radiate to the centre. The steining to be carried 5 feet above ground level, or farther if found necessary. The concrete of which the blocks are to be made must be properly prepared, and mixed in machines approved by the Executive Engineer, and the component parts to be of the following proportions, *viz.*:—Portland cement 1 part, river sand 4 parts, and broken stone 6 parts.

Behind the steining there will be 3 feet of broken stone backing, hand-packed. The stones to average 4 inches each way.

Dry Backing.

The parapet walls of two wells are to be built above the steining, of good coursed rubble work 18 inches in thickness, set in good lime mortar. The stones to be flat-bedded and hammer dressed. The headers in each course not to exceed four feet apart, and to go right through the wall. The wells which contain the valve shafts are to be finished 25 feet or thereabout above plinth level; the walls of the other wells to be finished at 5 feet above the plinth level.

Parapet.

Arches are to be thrown over the door and window openings, as shown on the drawing. All joints of the rubble work to be scraped out, and neatly pointed after the work is finished.

The cornice to be of ashlar, finely dressed, and carefully laid, as may be directed.

Cornice.

The mortar is to be composed of fresh burnt lime of the best quality, and clean sharp sand, free from salt, mixed in the proportion of one of lime to 1½ of sand, or in such a manner as the Engineer may direct, all well mixed and tempered with the proper quantity of water in a pug mill, and only to be ground as required for use. Any mortar that has become hard, or that is partially set, will not be allowed to be used in the work.

Mortar.

The sand must be carefully screened, if of a coarse nature, before being used.

After the parapet walls have been carried up to the proper height above ground, as above stated, the wells are to be roofed in as shown on the drawing, and will consist each of two wrought-iron girders, with teak joists and planking 1 inch thick, on which is to be laid 6 inches of concrete, and the whole covered with half an inch of Portland cement, in the proportions of 6 of sand to 1 of cement.

Roofing of wells.

A man-hole must be left in the roof of each of the outer wells, to give access to the interior.

A cast-iron valve shaft is to be erected in the centre of each of the two inner wells, as may be pointed out, and according to the drawings, and to which the slide valves are to be attached. The cast-iron shaft is to be four feet diameter inside, and to consist of the necessary number of flanged cylinders, six feet long and one inch thickness of metal each. All the cylinders to be firmly bolted together through the flanges, which are to be 1½ inches thick, the faces of which must be properly planed and faced to secure a water-tight joint.

Valve Shaft.

The shaft is to rest upon and be bolted to a cast-iron plate, one inch in thickness, well-fitted into ashlar blocks, as shown on the drawing.

The quality of the metal used in the valve shaft to be as afterwards described for main and distribution pipes.

Three 2½-inch sluice valves are to be fixed at the heights shown on the drawing.

Sluice Valve.

A branch pipe will have to be cast on outside of cylinder, to which the main delivery valve will be attached as shown.

Main Delivery Valve.

These valves are to be of the very best description and finish, the faces to be of gun-metal, of at least half an inch in thickness, and fitting true and close, the case to be of cast-iron, the screws to be of wrought-iron, the screw bush to be of brass, and the rods to be of steel.

The case of the valves to be made in two pieces, properly bolted together, to allow of easy removal at any time. The rod will work in clamped guide brackets as shown, the front of the brackets being made moveable, to enable the rod to be unshipped at any time. All the valves are to be worked from the platform at top of the valve shaft, by a screw in a pillar as shown; the screw bush must also be made into two parts. The main delivery valves to have ring frames with wire netting in front. The valve rods will be 2½ inches in diameter.

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The platform at top of valve shaft will be as shown, extending from the shaft to the side wall of well, and will be supported by two wrought-iron girders as per drawing. The floor of the platform will be laid with pucka teak joists and planking, the joists to be 6 × 2½, and the flooring to be one inch thick, grooved and tongued; no board to exceed 7″ in breadth, and all to be fastened with 2-inch screw nails. A good strong teakwood railing will have to be erected all round the platform, as shown on drawing.

Platform.

All the timber to be used will be Moulmein teak, sound-hearted, hard, compact, free from sap wood, shakes or sun cracks, and shall be the full dimensions specified, without any patching or plugging whatever.

Timber.

All joints and framing shall be made and fitted in a workmanlike manner, and in accordance with the drawings furnished to the contractor, and to the satisfaction of the Engineer; and if after the wood work shall have been erected, any undue shrinkage, or bad workmanship, show themselves, the contractor shall forthwith amend the same.

The doors at wells will be framed 1½ inch thick, bead and flush outside; with three inch ledges on the back, hinged with 3 five-inch brass hinges, and furnished with locks and keys complete.

Doors and windows.

The windows will be simple glazed frames, 1½ thick, fitted with venetians, and are to be hung with two 3-inch brass hinges each; the venetians to open outwards, and the glazed frames to open inwards.

The whole to be furnished with the necessary furniture and fastenings complete.

The price for doors and windows of every description must include all necessary frames, locks, bolts, hinges, fastenings, and furniture requisite to make the work complete.

The rain water which falls on the roof of the wells will be led by 6-inch cast-iron pipes into the well. The pipes will be fixed to the walls inside by suitable iron clamps.

Twenty-four inch pipes, ¾ inch thick, are to be laid from the main delivery valve, to connect the wells and conduit, and are to be of the quality and description and laid in the manner which will be afterwards described for the Main and Distribution Pipes, and at junction with culvert are to be provided with flanges, bonnet pieces, bolts, washers, and nuts necessary for closing the mouth, when required.

Main delivery pipes.

2.—Culverts.

The excavation for the culvert is to be taken out to the depth shown on the section, or as may be directed, and of the width shown on the drawings of culvert, and will extend in length from the wells at the Malir to the inlet well near Karachi, a distance of nearly eighteen miles.

Excavation.

In measuring the quantity of excavation to be paid to the contractor, the figured dimensions only of the culvert will be allowed for the width. The contractor will have to satisfy himself, as in the case of the wells, regarding the amount of water he is likely to have to contend against, and the nature of the material in which the excavation has to be made, and estimate accordingly.

Dimensions.

The tender will include all machinery that may be required for pumping, and all materials for shoring, strutting, &c., and all labour necessary for the due completion of the contract to the satisfaction of the Executive Engineer in charge.

Before any masonry is built in the excavation, the foundation will have to be carefully examined and approved of by the Engineer.

Attention will have to be paid to the gradient marked, so that it may be carefully adhered to.

The culvert, where not in rock-cutting, or where the Engineer may direct, is to be built on a good foundation of concrete, composed of broken stone, sharp sand and lime in the following proportions, *viz.*:—4 of broken stone, 2 of sand, and 1 of lime. These are to be accurately gauged, and the materials mixed in a dry state. They are then to be moistened and well-beaten, until a thorough admixture of all the parts is effected, and the mass brought to a tough consistency, when it is to be immediately filled into baskets, spread in the trench, and then rammed.

Foundation.

The side walls of the culvert are to be built of common rubble work, 12 inches thick; no course to be more than 12 inches high; all the stones to be parallel-bedded, and to go right through the wall; the joints must be well-filled with mortar, and the whole grouted throughout.

Side walls.

The culvert to stand the dimensions marked on plan after the cement lining, which will afterwards be described, has been put on.

The covers are to be not less than 8 inches thick and 1 foot broad, of good, sound stone, dressed only on bed and joints, so as to lie close, set in mortar at the bearings, which will be not less than 6 inches at each end.

Covers.

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The bottom of culvert is to be laid at the radius shown, of good sound blocks, not less than 6″ × 9″ × 1′, set in good lime mortar, each stone set hard to hard at all joints, the key driven in tight, and the whole afterwards grouted thoroughly with thin lime mortar.

Arch in rock cutting.

In cuttings where rock of a suitable description is found, the side walls and invert will be dispensed with, and an arch will be turned at top of rock, so as to save filling in after the work is complete. A proper skew back having been cut by the contractor, the arch is to be turned as shown on plan of culverts, built of good block-in-course masonry, the beds and joints hammer dressed, and all set in good lime mortar. The arch stones must be cut, so that they will radiate to the proper centre.

The price per 100 cubic feet of arching to include cutting, skew backs, and all centering that may be required.

Ventilating shafts.

Ventilating shafts are to be built where shown on section, or wherever the Engineer may direct, and are to be of good common rubble masonry underground, as described for the culvert, and of block-in-course above. No stones in the block-in-course work to exceed in height of course the breadth of bed.

Cast-iron ladders.

All ventilating shafts are to be provided each with a ladder, fastened from top to bottom by proper staples, built into the masonry, to afford to the workmen means of ascending and descending while repairs have to be effected.

Syphons.

If syphons are found necessary on any part of the work, the masonry connected with them will be of the quality and description of common rubble already described, and the pipes will be of the quality and description afterwards specified for the main service and other pipes. If clay puddle or concrete may be required, the same will have to be supplied by the contractor, as described for those required for other portions of the work.

Lime.

The lime is to be of the best quality, as may be approved by the Engineer, to be brought on the ground unslaked, and to be reduced to an impalpable powder before being slaked.

Mortar.

The mortar shall consist as above of lime of the best quality, to be approved by the Engineer, and clean, sharp sand in the proportions, and mixed in the manner already specified for the parapet walls of wells.

The mortar in every case to be ground in a mill before being used. No mortar which has become hard or partially set will be allowed to be used in the work.

Proper arrangements must be made for keeping the work well-watered.

Cement lining.

After the side walls and inverts of the culvert have been properly cleaned, a coating of Portland cement, half-inch thick, is to be laid on to the extent to be afterwards determined by the Engineer in charge.

The cement plaster must be composed of one part of cement to three of sand.

The whole will be laid on flat, and carefully smoothed and brought to one uniform surface, the whole length of the culvert, or as may be directed.

The contractor must only obtain his cement from manufacturers well-known to supply only a first class article, and to be approved in writing by the Engineer. The cement must be stored in a suitable shed, built by the contractor for the purpose, and each consignment shall, on its arrival, be subjected to the following test, and if the result be found unsatisfactory, the cement shall be rejected. No cement shall be used in the work till the result of the test is known.

Tests.

All cement must weigh at least 112 lb per bushel ground dry; it must be capable of passing through a fine hair sieve; when mixed neat it must be capable of setting hard in water in seven days, at the expiration of which time it must bear a tensile breaking strain of not less than 280 lb to the square inch.

The contractor must be careful to repair at once all blown places on the cement plaster, or places where the surface has scaled off.

3.—Inlet Well.

The inlet well, which is to be built near the site of the reservoir, is to be finished 20 feet in diameter, and 15 feet deep, or thereabout, as may be directed.

The steining is to be of ashlar, 2 feet thick, and must be laid with header and stretcher alternately, all as described for the concrete blocks of the wells at the Malir. All the stones

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to be truly dressed on all beds and joints, and the whole made to radiate to the proper centre. The whole to be set in cement mortar composed of one part of Portland cement and two parts of clean sharp sand, thoroughly mixed with only such a quantity of water as will make the whole a plastic mass; each course after being set, will have its joints carefully grouted with the same cement mortar, but with the addition of such a quantity of water as will render it fluid and capable of penetrating the work.

Clay puddle.

Backing of clay puddle, 12 inches thick, is to be well-rammed behind the ashlar wall and puddle, is also to be laid over the bottom of the well, on which ashlar blocks, 12 inches thick, are to be laid. All the clay puddle required must be properly worked up on the ground before being put into the work, all stones, sand and gravel, earth or other foreign matter must be carefully excluded, and the whole worked up into one plastic, homogeneous mass of the toughest consistency, and placed in the work in layers not exceeding 6 inches thick.

Pointing.

The whole of the joints of the ashlar work are to be scraped out 1 inch in depth and carefully pointed with cement; a suitable arched opening will have to be built in the steining of the well, at the point where the culvert ends.

The parapet walls of the wells are to be continued 18 inches thick to a height of about 10 feet above ground level, to be built of good block-in-course and lime mortar, and the whole to be finished with an ashlar cornice, and covered with pucka teak planking and joists and cement concrete, as described for the Malir Works. Three-inch cast-iron pipes will also have to be provided and fitted up in the well to carry off the rain water. Doors and windows will also be provided as described for the other wells.

Flooring joists are to be laid over the well at about ground level, and ¾ inch grooved and tongued boarding, fixed with 1½ inch brass screw nails, laid on the top; the board not to exceed 4 inches in breadth.

In the inlet well will have to be erected a 24-inch cast iron over-flow stand pipe, connected with the cleansing pipe, leading into an open channel, some distance from the well. The top flange of the over-flow pipe will have to be carefully erected at the level directed by the Engineer. The cleaning pipe, at a little below the bottom of the well, will be fitted with an ordinary 24-inch sluice valve.

The main distribution pipe is, for the present, to be connected with this well, and is to be for a distance of 20 yards, or thereabouts, a 24-inch pipe; thereafter reduced, by an ordinary reducing piece, to 10 inches diameter. The 24-inch main at the well will be supplied with a sluice valve, as shown on drawing. This, with the cleansing valve, to be worked from the platform at ground level; suitable provision being made for fixing the pillars in which the screws will work, all to be as described for the Malir wells. The valve of the main delivery pipe in the well will be protected by a strong frame, with wire gauze netting in front.

A house for sluice-keeper, as shown on plan, will have to be built of good coursed rubble and lime mortar, as already described, and roofed, in the usual manner, with pucka teak and tiles.

4.—Main Service and Distributing Pipes.

Main service.

A main service pipe, 10 inches diameter inside, and half an inch thick is to be laid from the reducing piece near inlet well, along the route shown on the plan.

Sub-mains.

The sub-mains are to be laid along the streets and lanes in Town and Camp as shown on the plan. All to be of the size and thickness marked, and fitted with the best description of stop cocks, scouring cocks, air valves, hydrants, stand pipes, &c., necessary for completing the water-supply of Karachi in a first class and workmanlike manner. The whole of the pipes (except at junction of stand-pipes, hydrants, &c., and where specially ordered, which will be flange pipes) to be socket pipes.

Description of metal.

All the pipes to be of the very best grey metal re-melted from the cupola and to be perfectly free from flaws, to be cast vertically in dry sand moulds, socket downwards, and to be of uniform bore and uniform thickness of metal throughout, and without any belts. The core barrels for all pipes to be expanding iron core barrels, the same or similar to those known as Wright's expanding core barrels. The whole of the pipes are to be proved under a pressure equal to a column of water 400 feet high, and each pipe, whilst under pressure, must be rapped from end to end with a hammer, so as to discover any porous, blown, or sandy places in the metal; the weight of the hammer to vary from 4 to 7 lb according to the size of the pipe and the thickness of metal in the casting. The Karáchi Municipality shall be at liberty, if they so think fit, to depute an Inspector to be present from time to time at and to assist in proving the pipes, and the contractor shall afford such inspector every facility in the performance of this work.

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Should any pipe on examination, or when undergoing such test, be found defective, or to be in any way inferior to the description of water pipes required and described in the specification, it shall be rejected and replaced by the contractor, at his own expense, by such other pipes as may be found upon examination and the aforesaid test, to fulfil all the conditions of this specification.

Special castings. The curved pipes and other special castings shall be executed according to drawings which will be furnished. They must be of same thickness of metal as the straight pipes, and care must be taken that they will properly joint with the straight pipes and other castings with which they may be intended to connect.

Joints. The pipes to have, principally, turned and bored joints, but 20 per cent. to have wide socket joints for lead.

Coating with pitch. All pipes to be carefully coated inside and out with coal pitch and oil, according to the process introduced and patented by Dr. Angus Smith of Manchester; the pipes, when cold enough, to be trimmed and cleaned, and after all particles of sand and loam, and other extraneous matter, have been removed from the surface of both the inside and outside of the pipes, and while quite dry and free from rust, shall be covered all over the surface, both inside and out, with linseed oil, and then shall be kept quite dry until immersed in hot pitch; the pipes, after having been cleaned and oiled, and after they are cooled down to within 20 degrees *Fahrenheit* heat of boiling pitch, or, if allowed to get cold after being cast, after being heated equally all over in a furnace to twenty degrees above the temperature of boiling pitch, and whilst at the aforesaid temperature, shall be dipped vertically in a bath of boiling pitch, or of pitch mixed with linseed oil contained in suitable pans, surrounded by heated flues to maintain the boiling temperature of the pitch.

The pipes, after being immersed a suitable time, shall be very slowly withdrawn from the bath in a vertical position, so as to allow as much pitch as possible to drain off, and the pipes shall be kept in a vertical position until they are cooled down to the temperature of the air.

Length of pipes. Every straight pipe shall measure 12 feet when in the work (*i. e.* exclusive of the inner depth of the socket), and no pipe shall deviate from the mean rate at which it is estimated more than 2½ (two and half) per cent. In cases of under-weight, the pipes will be rejected; in cases of over-weight, no payment will be made for such over-weight.

Immediately after being proved, each pipe shall have a wrought-iron hoop of the very best quality, formed of rectangular iron, ½ inch thick by 1 inch wide, soundly welded and shrunk firmly on the spigot end, within ½ an inch of the end; this hoop is intended to prevent the spigot ends of the pipes being split or broken in transit.

Laying of pipes. In excavating the trenches for the main and street service, the metalling must be first taken off the roads and laid on one side of the trench, and the earth on the other side. In refilling the trench, the earth must be well punned in, in layers not exceeding six inches in thickness, and watered if necessary. The metal will then be spread and the whole rolled smooth.

Excavation. In excavation crossing roads, no more than half the road will be allowed to be opened at one time. The surplus earth to be carted away by contractor, and deposited where the Engineer may direct.

Protection of open trenches. Open trenches must be protected by a bamboo or other fence by day, in addition to which a sufficient quantity of lights (red or otherwise) must be maintained at night.

The Engineer will have the power to order watchmen at night at the expense of the contractor, if he considers this necessary.

Depth under ground. The main service pipe is to be laid at such a depth that it will not be nearer the surface of the ground at any part than 2 feet.

The sub-mains to be laid so that the pipes are not nearer the surface of the ground at any part than 18 inches.

Jointing. All the pipes are to be carefully laid and jointed, the turned and bored joints with red lead, anti-corrosion paint, &c., and the wide joints with lead and white yarn, the yarn to be tallowed and well-caulked into the sockets; the lead is in no case to be less than 2½ inches deep, run entirely around the pipe, and every joint is to be set up, when cool, ⅛ of an inch within the socket. All flange joints are to be properly made with lead-lapped rings secured with bolts and nuts, and afterwards, if necessary, run with lead; all to be executed in a good, workmanlike manner, similar to the work performed in Bombay, or other places where a first class water-supply has been carried out.

The price given in the schedule of rates for laying and jointing per lineal yard, to include the making of all connections of whatever description which may be required in the course of the work.

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Sluice valves.

All the sluice valves of the various sizes required are to be of the best description and workmanship, with double faces, and keys, &c., complete. The faces, screws and nuts to be of gun-metal, and the stuffing glands bushed with brass. The faces of the valves to be accurately planed and brought to a bearing and proved to a pressure of 600 feet of water.

Hydrants.

The hydrants are to be fitted with surface boxes, level with the roadway, as shown on drawing; a stand pipe, with single revolving discharge outlet, is also to be supplied, to be screwed on to the nose of the valve, and a long handled key to turn the water on and off. The number of hydrants, stand-pipes, and keys will be afterwards determined.

The hydrants to have the valve seatings of brass, with screwed nose of gun-metal, 2 inches diameter.

Stand pipes for street watering carts.

Fluted stand-pipes of cast-iron are to be erected of the pattern shown on drawing, with 2-inch valve on the head, opened by a loose key; the screw for hose union is to be of gun-metal, fitted with an iron cap and chain.

Street wells.

Wells are to be erected along the various streets, as may be directed; the case to be of cast-iron fluted, as shown, with basin at bottom and drinking cup complete, and must be on the waste preventing system.

Street services.

These services are to be erected along the various streets according to the drawing, and where may be directed. They are to consist of rows of 1½″ self-acting bib cocks, fixed on 4-inch pipes built into masonry. Air cocks will have to be erected on these services, or where may be considered necessary.

In connection with the street services, and at the distance of a few feet on one side, will be built a water trough, say 5 feet long by 2 feet wide, to catch the overflow from the services.

Bullock services.

The bullock services will be constructed of 4-inch pipes, supported on pillars of masonry, supplied with ball cock and air valve complete, as per drawing.

Meters are also to be furnished and fitted up where required; all the sluice valves, cocks, meters and other fittings to be of the same quality and description as those manufactured by the Glenfield Company.

All the exposed wood and iron work, such as street wells, troughs, stand-pipes for street watering, stand-pipes for hydrants, and the like, to receive three coats of good lead and oil paint, of a plain color, as may be directed by the Engineer.

Wells of masonry set in lime mortar will have to be built, for all sluice valves, hydrants, &c., and made to fit the cast iron covers.

Scouring cocks are to be placed where required, and a pitched channel will have to be made leading into the nearest watercourse or ditch.

GENERAL CONDITIONS.

1. Schedules of quantities have been prepared and are attached to this specification, dividing the work into various contracts. Contractors in tendering for any of the contracts must attach a rate to each item in the schedule of work pertaining to that contract, which must be the rate at which he will agree to execute not only the quantities given in the schedule aforesaid, but any further works of the same description belonging to this water scheme.

2. The contract itself is not to be vitiated in any respect by any error of any kind in the survey, information, specification, drawings and bills of quantities. It is also to be understood that the drawings represent the nature of the works to be executed and not necessarily the works as they will actually be executed; further drawings of which will be issued to the contractor as required.

3. All payments will be made to the contractor in the Karachi Municipal Office, and in the ordinary currency of India, or in legal tender for the same, without allowance of any kind on account of exchange, transport, or other charges of a like nature.

4. It is to be understood that throughout this specification and the documents of every description connected therewith, the person referred to as the "Executive Engineer" is the Engineer in the service of the Municipality, and appointed to take charge of this work.

Securities and payments.

5. The contractor shall find two good and responsible securities each for the amount of ₹10,000 for contract No. 1, ₹5,000 for contract No. 2, and ₹3,000 for contract No. 3, who shall jointly and severally enter into a bond to the Municipality at the time the contract is signed, for the due performance of the same, in strict accordance with all and every of the terms and provisions thereof.

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6. The contractor for contracts 1 and 3 shall deliver to the President of the Municipality for the time being on the expiry of each calendar month, an account of the extent or amount and value of the work which shall have been executed during the month; such measurements to be determined by the contractor and the Engineer going over the works and ascertaining by actual measurement the quantity of work executed, and the said President of the Municipality shall, within 14 days after the delivery of such account, pay ninety per cent. of the amount which the Executive Engineer shall certify until the sum thus retained shall amount to ten per cent. of the contract; after such time the whole amount of monthly certificates shall be paid. The contractor for No. 2 contract shall, on the arrival of the material under this contract in Karachi Harbour, and on his handing over the same to the contractor under No. 3 contract, receive from the Municipality the value of such material calculated in rupees according to the rates given in his tender.

The total amount of the sums deducted for the 10 per cent. retention under contracts 1 and 3 shall also be returned by the Municipality without carrying interest, and three-fourths of the same shall be paid to the contractors within three months after the completion of the work has been certified as above; the remaining one-fourth to be paid at the expiry of the year of maintenance.

7. It shall, however, be distinctly understood that the periodical certificate of the Engineer for payments shall not be held to signify an unconditional approval of the whole of the works or material included in such certificates and that the contractor will not be relieved from any risks or liabilities to which he may be subject under the terms of his contract, until a final acquittance shall have been given him under the last certificate provided for in the previous clause.

8. Notwithstanding any custom to the contrary, nett measurements only will be allowed and paid for upon all works executed and materials delivered in accordance with the specification and general conditions; and all prices given in the schedule attached hereto shall include labour and materials, unless otherwise specially specified in the case of any particular item.

9. The contractor is to provide and defray the expense of all implements and plant of every description that may be requisite for carrying on the works with despatch and completing them with efficiency, and generally shall provide and defray the whole expenses of every thing required for the execution of the works, the laying out and measuring up of the same.

He is to pay all taxes and duties which are now or may at any time, during the execution of the contract, be leviable either of goods to be provided by him imported into India, or upon goods provided by him, or upon, stores or other materials obtained in the country.

10. Should the carrying on of the works lead to infringements of the Indian Penal Code, in consequence of the illegal or riotous proceedings of the labourers, foremen or others, to such an extent as to necessitate the employment of special extra police, the cost of such extra force is to be defrayed by the contractors.

11. In all cases where the dimensions are given on the drawings or stated in the specification, such dimensions must be worked to in preference to measurements by scales, which are to be used only where no dimensions are stated.

12. The contractor must provide at all times an efficient staff of trusty, skilful and experienced European Assistants.

It shall be in the power of the Engineer to direct the prompt dismissal of any such members of the contractor's staff he may consider inefficient, or in any way unqualified for the post they occupy.

The contractor must at all times employ as much labour of every description as, in the opinion of the Engineer, is necessary for the proper and timely completion of the works.

13. The Engineer shall have power to test or cause to be tested, as the work goes on, any such portions of it as he may think fit, in order to prove their soundness and sufficiency; and in case any portion of the work shall, with or without testing, be considered defective or imperfect, and not in accordance with the drawings and specifications, or in any other respect unsatisfactory, the contractor must, upon receiving notice to that effect from the Engineer, forthwith amend or re-execute the same in a proper and satisfactory manner.

The Engineer shall at all times have the power to make the contractor remove at his own expense, to such a distance from the works as the Engineer may deem expedient, any work or material he may consider unfit, inferior or unsound, and in the event of the contractor refusing to obey the written orders of the Engineer, he shall have power to pull up, break down, or otherwise remove the objectionable work or material, and the expense incurred in so doing will be deducted from the next certificate of the contractor.

14. No material found in the excavation shall be used by the contractor otherwise than in the works.

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15. The Engineer shall have the power of directing the order and manner in which the several works shall be proceeded with.

16. Right is hereby reserved to the Engineer to make any alterations or additions to the designs, or to enlarge, diminish, or in any way alter the work, as he may consider necessary.

Such enlargements, diminutions, alterations or additions shall in no degree affect the validity of the contract, but shall be performed by the contractor under the same conditions, stipulations and responsibilities as if they had been originally and expressly included and provided for in the specification and drawings, and their value shall be estimated according to the schedule of prices sent in with the tender.

17. For any kind of work not specially mentioned in the schedule, the price shall be fixed by agreement between the contractor and Engineer, and afterwards submitted to the Managing Committee of the Municipality for final sanction.

In the event of an agreement not being come to between the Executive Engineer and the contractor, the question shall be referred to the Superintending Engineer in Sind. If the contractor still declines to accept the rate fixed by the Superintending Engineer, the Executive Engineer shall have power to appoint other parties to do the work.

No claim for extra or additional work will be allowed (however the necessity for such may have arisen) unless specially ordered in writing by the Engineer, which orders the contractor must produce as vouchers for the charge; the vouchers for these extra works must be produced monthly, and the non-delivery of such will be considered as conclusive proof of the non-existence of such claims against the Municipality, and will be a full and complete exoneration in respect of the same.

18. If during the progress of the works, the contractor shall at any time suspend, or allow to be suspended, the execution thereof, or shall fail to proceed with the same with diligence, expedition and efficiency, and in such a manner as to satisfy the Engineer that the works will be completed by the specified time, or if the contractor shall omit or fail in any respect to carry on the works in a workmanlike manner, or refuse or neglect to comply with any order or directions given by the Engineer, or shall in any other respect act contrary to the terms of the contract, or to the requirements of the specification, the Engineer shall have power to suspend or stop all advances of money to the contractor on account of the works, until he shall do what is required of him to the satisfaction of the Engineer; and in the event of his neglecting or failing to do so during a period of eight days after the date of a written notice from the Engineer to be given to him or delivered, or left at his office as aforesaid, stating the ground of complaint against him, the Engineer shall have power immediately and without any further notice or judicial authority to take possession of the works, materials, stock, plant, &c., on the ground or works, and to carry on the works until the contractor shall satisfy the Engineer that whatever may be required as aforesaid shall be duly done by him, and to use for that purpose the materials, stock, &c., so taken possesion of free of all cost and charge, and of all liability for loss, deterioration, damage or injury thereto, and the cost of all such further materials, and of all labour and other charges which may arise shall be deemed incurred on the contractor's account, the work so performed shall be carried to his credit at the prices named in the tender, and the payments made on account of the same shall be charged against him or deducted from the first monies payable to him, and he shall not be entitled to question the amount or propriety of payments so made.

In the event of the contractor not doing what is required of him as aforesaid, for a period of one month after the date of the notice given to him or left at his office, or of his becoming bankrupt or insolvent, or of his suspending payment, or compounding with his creditors, or from any cause whatever, becoming unable to carry on the works efficiently, the Engineer shall have power, on the occurrence of any of these events, and without any notice being given to the contractor, or judicial authority, to take possesion of the works, materials and plant and wholly or in part as he may think proper; or, if he shall have previously taken possession thereof, to retain the same and to carry on and complete the work by his own servants and workmen, or to relet the same or any part thereof to such other contractor, at such price or prices, and on such terms as he shall think proper, and all sums of money retained by or then in the hands of the Municipality, or due, or to become due by the Municipality to the contractor in any way, together with the value of all works done, as well as the whole materials, stock, plant, &c., and the contractor's whole right and interest therein and otherwise in or under the contract in any manner or way, shall without prejudice to the Municipality's claims against the contractor and his sureties be fully and absolutely forfeited to the Municipality, in liquidation of damages incurred through his failure, and neither the contractor, his assignees or trustees or other person whomsoever acquiring right to or interest in his estate, or representing him in any way whatever, shall have any claim thereto.

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19. Should any dispute or difference of opinion arise between the contractor or any person in his employment regarding the execution of the work, the meaning of any clause or term in this specification, the quality of the materials, or of any part of the plans or drawings or otherwise, the same shall be referred to the Superintending Engineer in Sind, whose decision shall be final and binding on all parties.

But in all cases of such reference, the party making it shall do so in writing, and the award of the said Superintending Engineer in Sind for the time being may be made a rule of Court by either party.

20. The contractor must furnish to his assistants on the work a copy of this specification

21. The contractor shall not, on any pretence whatever, sub-let or assign the contract or any portion of it, to another party, without the special permission of the Engineer.

22. Payments will be made for materials deposited on the ground to the extent of three-fourths of the value of such materials.

23. The works will be set out by the Engineer appointed by the Municipality, who shall give all levels and lines necessary, but the contractor must provide and pay for all labour, stakes, pegs, posts, ranging rods, or such other marks or apparatus as may be required for setting out the works.

The setting out of the works is understood to include all cutting of nicks or trenches to indicate boundaries. The contractor must satisfy himself of the correctness of all setting out, as the Municipality will not be responsible for any errors.

24. The contractor shall be bound to complete the whole of the work comprised in this contract, with such alterations and modifications of the designs or materials as may be directed by the Engineer at any period during their construction, by the dates specified on the different schedules of quantities.

25. But if any additions are ordered which, in the opinion of the Engineer, shall materially increase the magnitude of the works, then such addition to the contract time shall be made as shall appear to him to be reasonable under the circumstances.

26. The works embraced by this specification are divided into three contracts, as per the schedule of quantities attached.

The first contract includes the supply of all materials and labour required in the construction of the works from the Malir wells to the inlet well near Karáchi, but exclusive of the supplying of the iron work of the valve shaft and valves in the Malir wells, the piping between the wells and the junction tank, the syphon piping and the valves and piping at the inlet well. The erecting, fitting, laying, jointing, &c., of the above is included in this contract, together with all unloading, landing, customs or other charges, and all carriage over the works.

The second contract includes the supplying of the following :—

Cast-iron pipes of sizes, valve shaft and valves, sluice valves of sizes, and all other fittings and appurtenances required. The price to include all charges free on board in Karachi harbour.

The third contract includes the laying and jointing of all main and distribution pipes from the inlet well inwards, the fitting of all valves, erecting all hydrants, stand-pipes, street services, &c., and their appurtenances which may be required.

The works under contracts Nos. 1 and 3 are to be maintained by the contractor for a period of twelve months from the date at which a certificate is given in writing, by the Engineer, to the President of the Municipality, that the whole of the works under that particular contract have been completed in a satisfactory manner.

The contractor is to be answerable for the stability and permanence of the works, and for the regular and proper supply and flow of the water both in the culvert and pipes for the period above mentioned, and is to hold the Municipality free of expense for any damage done to the works by floods or from any cause or accident whatsoever.

He is immediately to repair all damages or injuries to the works or imperfections therein, and he must keep every part of the works in thorough repair to the entire satisfaction of the Engineer. Should the contractor fail to maintain the works or execute any repairs required by the Engineer, the latter will execute whatever work may be necessary, and deduct the cost from the portion of the 10 per cent. retention in the hands of the Municipality.

27. Should the contractor fail in any way to carry out, when called upon to do so, the maintenance, as specified or, to the satisfaction of the Engineer, the latter may employ what labour and materials he may consider necessary in order to carry out such work, the cost to be borne by the contractor.

28. Tenders must be in sealed envelopes marked outside "KARACHI WATER-SUPPLY," and addressed to the "President" Karachi Municipality, and lodged at the Municipal Office on or before the 8th December 1879.

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alternative lines were accordingly surveyed and estimated for. In connection with the alternative line round the spur, the site of the dam, which had at first been chosen with regard to

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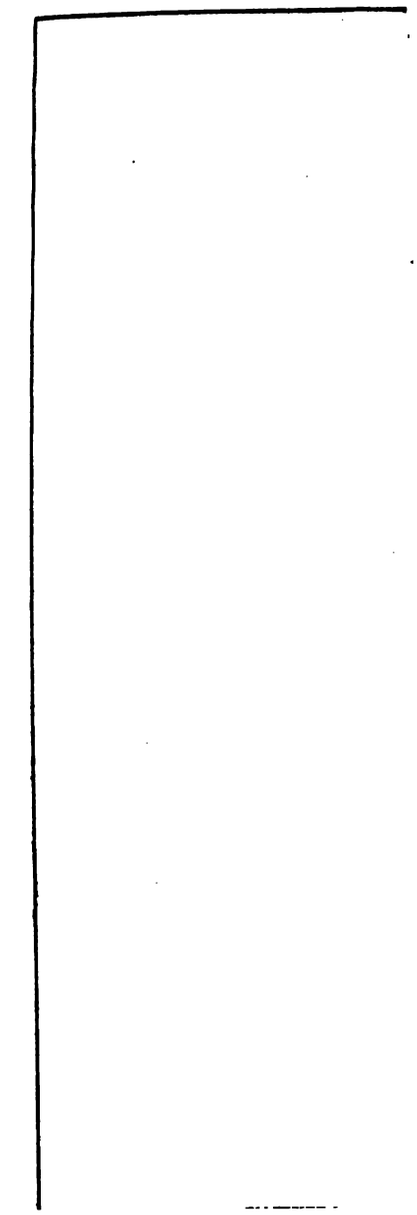

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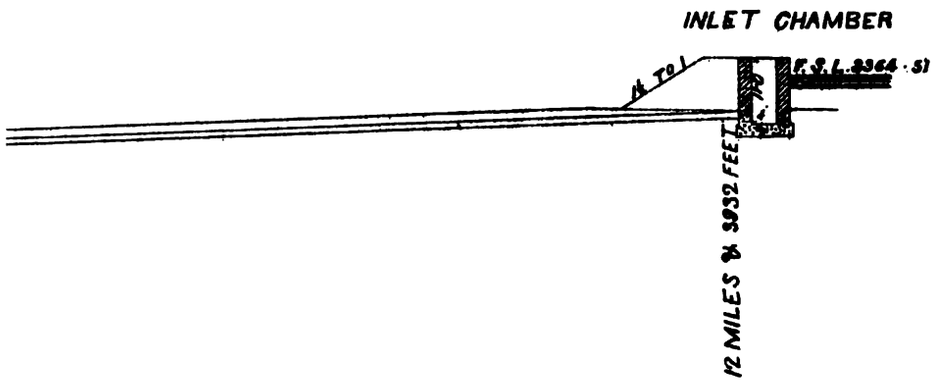

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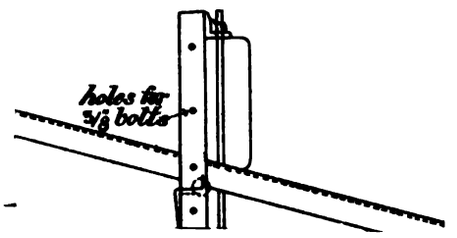

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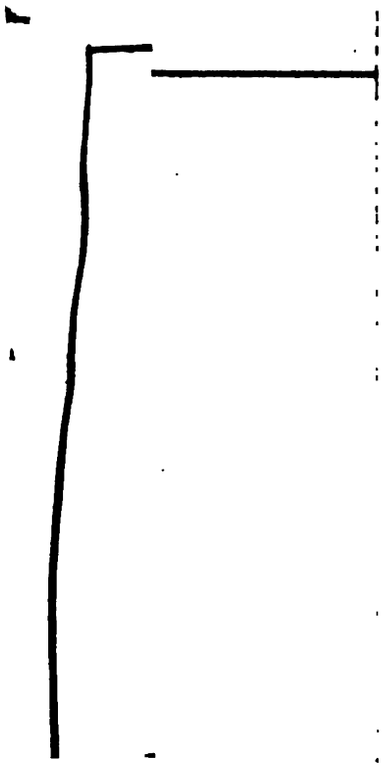

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the tunnel, was altered to a place situated lower down the valley, where the gorge was narrower, thus providing a cheaper bund and better storage tank. The plans and estimates were entirely revised, with the exception of the last portions, beyond the Yevteshwar Khind, which had already been commenced, and which must have remained the same whichever side of the spur the line was taken. Colonel Smith, R. E., was confident that the revised line would not exceed in cost.

The sanctioned estimate and works were accordingly commenced before the line had been completely surveyed and estimated for. At this period Colonel Smith, R.E., proceeded on furlough, at the conclusion of which he retired from the service, and he was succeeded in his post by Mr. Davidson, who carried the works out to their finish. On a careful survey being made of the new line, it was found that the works required would be of a much more extensive nature than it was at first supposed, and the final sanctioned estimate, as per Government Resolution No. 3 C. W.—33 of 15th January 1885, amounted to Rs. 3,10,923. During the construction of the works, considerable damage was done to the works by the heavy rainfall, and modifications, repairs, and additional works were necessarily required, which raised the estimate to ₹3,71,478.

The work has been finally completed at a cost of ₹3,65,163, distributed as follows:—

	₹
Works	3,10,753
Establishment	45,406
Tools and Plant	9,006
TOTAL	3,65,163

Funds from which the work was executed were:—

	₹
Provincial	63,747
Local	35,000
Municipal	2,66,416
TOTAL	3,65,163

Tank at Kas and head-works.

9. The Satara water-supply consists of a tank at the head of the Urmuri river, a feeder of the Krishna river, situated in a high valley, 3,692 feet above mean sea level, at the junction of the spurs running along the Koyana and Yenna valleys up to the Mahabaleshvar plateau, with an open channel, 15 miles, 1,391 feet long, from the tank to the connection with the old works at Yevteshwar hill, above the town of Satara. The drainage area of the tank is 1 mile, 97 square feet including the area of the tank, namely, 3,373,000 square feet, and the average rainfall is 139·67 inches. This rainfall, however, has only been gauged at the tank site, and as the run-off has been gauged to be greater than the rainfall, the natural inference is that the rainfall on the hills in the catchment basin is very much larger than at the tank site, and, therefore, the percentage of the run-off to the fall cannot be arrived at.

10. The soil of the catchment basin is laterite, bare at the top of the hills, but covered on the slopes with scrub jungle, and the catchment area is now uninhabited, and is chiefly under the Forest Department.

	C. feet.	C. feet.
11. The available contents of the tank at full-supply level are		56,567,362
And the loss by evaporation is calculated to be	12,600,836	
Loss by leakage	6,000,000	
		18,600,836
Leaving available supply		37,966,526

The loss by leakage will doubtless decrease as time goes on. This, however, represents a daily supply of 316,388 cubic feet, for 120 days, at the head, or 3⅔ cubic feet a second, thus ensuring a supply of at least 1 cubic foot a second at the tail, or 22½ gallons a head for a population of 24,000. The amount of the supply will be according to the efficiency of the state in which the canal is kept by the Municipality. The days above mentioned are supposed to be the number on which water will be required to supplement the Yevteshwar supply, namely, from 15th February to 15th June. Should, however, it be required to supply the town for a longer period, the storage powers of the tank can be considerably increased, by raising a temporary weir, on the waste weir, at the end of the rainy season.

Dam.

12. The dam is of the same class as the ordinary dams erected in the Deccan, except that the top width is 10 feet, and the slopes are 2 to 1 and 3 to 1, falling off from the top at once. The length of the dam

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is 718 feet, and its greatest height is 56·41 feet. The tower and culvert are of the usual pattern.

Waste weir.

13. The waste weir is cut through the laterite rock, on the east side of the dam; it is 60 feet wide at the centre, with a rapid fall on the lower side. It is calculated to discharge 5,400 cubic feet a second, equal to a run-off of 3″ per hour from the catchment area. The difference between the sill of the culvert and the top of waste weir wall is 17·80 feet, which represents the full supply of the tank.

Canal.

14. Directly the canal issues from the discharging basin of the culvert, it passes under the waste weir, which is here a steep channel, with a protecting wall on the bund side, and in cutting on the other.

The canal is calculated to discharge at full supply 5 cubic feet a second, and this section is maintained for the whole of its length. The general section is 1·3 feet bottom width, with slopes of 1½ to 1, and the fall throughout the line, except in particular places, is 4 feet a mile.

15. The peculiarity of the channel is that it is led along the steep hill sides, across the drainage of the country, over extremely hilly and bad ground, and only as the work progressed were the difficulties discovered and overcome, and, for this reason, general designs were sanctioned; and as each nala was approached, the one most suited to it was selected, and modified if necessary.

16. The class of works sanctioned were aqueducts, with wing walls straight in the line of the aqueduct, culverts, arched and slabbed, super-passages, corrugated iron aqueducts, earthenware pipe drains, iron pipe syphons, closed underground passages, and iron trough aqueducts.

Line of channel.

17. After leaving the waste weir, the channel proceeds along the precipitous side of the river gorge, and is carried on a high embankment, supported by a dry stone wall on the lower side, till it reaches nala No. 4, which it crosses by an inverted iron syphon, consisting of 12″ pipes, with masonry inlet and outlet. From this nala the line keeps along the hill side, crossing the drainage by ordinary works, except one deep nala, which is crossed by another iron pipe inverted syphon, till 4 miles 387 feet is reached, where the channel is turned into a convenient nala, and allowed to fall down the hill side to a lower terrace; here it is caught up, and again carried on through very rough country till it reaches the 9th mile near the village of Petri. Here the character of the hill changes, and instead of being in terraces, the laterite portion of the hill is very steep, and the channel is only a little above the perpendicular trap formation underlying the laterite. It was originally proposed to carry the channel along this portion, nearly a mile in length, by a covered channel, but it was found that this was impracticable, and a series of light iron troughs, supported by girders and dry stone wall protected embankment, were substituted for it. There are 66 spans of 20 feet on this portion of the canal, supported on masonry piers, and this portion of the work presents an almost unbroken line of aqueduct and high dry stone walling. After the 9 miles, 3,286 feet, the channel proceeds along terraces without any remarkable works, till the Khind, called Ganesh Khind, is met in the 12 miles, 4,959 feet. This depression is crossed by a long iron pipe or inverted syphon, and the channel afterwards proceeds along the Yevteshwar hill till it joins the old cistern, where the water is received into a settling basin and filter, from which it passes over into one of the old manholes on the line of culvert leading down the hill to Sátára.

Masonry works.

18. The following works have been constructed along the channel:—

Names of works.	Number of works in each type.
Culverts	79
Earthenware pipe drains	22
Aqueducts	41
Troughs on masonry piers	4
Escapes of one opening	18
Overbridges	6
Cast-iron pipe syphons	3
Pick-up weir	1
Trough aqueducts	3
Masonry closed channels	2
Spans of iron trough on girders	99
TOTAL	278

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Completion of the works.

The channel was practically finished in June 1885, but, owing to the heavy rainfall, several slips took place in the high embankments, and it was deemed necessary to alter the line at these places; therefore after the cessation of the rains, the several improvements were taken in hand and completed, and on the 15th April 1886, the water was successfully carried along the whole length of the channel without any damage. The Municipality had desired that a test of 15 days' continual flow should be borne by the channel before they would take over the work, and after this had been successfully carried out, the work was handed over to them, and immediately used, as the towns-people were suffering considerably from want of water. The Municipality reserved to themselves the right of inspecting the channel, after the cessation of the rains of 1886, and reporting on it to Government. The work had stood the monsoon of 1886 most successfully no damage being done beyond what might be annually expected.

19. It would be naturally expected that a water-supply taken from such a distant source along such a difficult country, exposed to a remarkable heavy rainfall, should be conveyed in iron pipes—and no doubt it should have been so—but the cost was prohibitive, and the Satara Municipality may be congratulated on their public spirit in sanctioning a work which was by many declared impossible to be constructed so as to stand the monsoon rains, and carry the small supply of water such a long distance in the hot weather.

20. The officers employed on this work during its construction were:—

Executive Engineers.

Major (now Colonel) Smith, R.E.
Mr. A. Davidson, Assoc. M. Inst. C.E.

Assistant Engineers.

Mr. D. George, C.E.
Mr. H. Landon, C.E.
Mr. H. F. G. Beale, C.E.

A. DAVIDSON, *Assoc. M. Inst. C.E.,*
Executive Engineer for Irrigation, Satara.

Satara, 23rd March 1887.

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